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The Mineralogical Society

(*INSTITUTED FEBRUARY 8, 1876.*)

WITH A SEPARATELY-PAGED APPENDIX OF

MINERALOGICAL ABSTRACTS

EDITED BY L. J. SPENCER, F.R.S.

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MINERALOGICAL SOCIETY

(*Instituted February* 3, 1876.)

BYE-LAWS[1]

1. The object of the Mineralogical Society of Great Britain and Ireland, with which the Crystallological Society was amalgamated on December 11, 1883, shall be to advance the knowledge of Mineralogy and also of Crystallography and Petrology.

2. The Society shall consist of Ordinary Members and Honorary Members.

Ordinary Members.

3. Every candidate for Ordinary Membership shall be proposed by two Ordinary Members, one, at least, of whom shall have personal knowledge of the candidate.

4. Elections to Ordinary Membership shall be made by the Council, and shall be confirmed at the ensuing general meeting by a majority consisting of three-fourths of the Members present and voting.

5. Ordinary Members shall pay an entrance fee of one guinea and an annual subscription of one guinea. Ordinary Members elected on or before November 13, 1900, shall be entitled to compound for the annual subscription by a single payment of ten guineas: Ordinary Members elected after that date shall be entitled to compound for the annual subscription by a single payment of fifteen guineas.

6. Annual Subscriptions shall be due on the first of January of each year, but members elected after the first of October shall not be required to pay a subscription for the then current year.

7. The name of any Ordinary Member whose subscription is more than two years in arrear shall be brought before the Council and an intimation that this action has been taken shall be communicated to the Member. After the expiration of at least one year from that date, the Council shall be empowered to erase the name from the List of Members.

[1] Adopted at the Anniversary Meeting of November 13, 1900, and modfied November 18, 1902, and November 7, 1916.

Honorary Members.

8. Twenty persons, non-resident in the United Kingdom, may be elected Honorary Members. They shall pay neither entrance fee nor annual subscription.

9. Every candidate for Honorary Membership shall be proposed by two Members of the Council, and the election shall be by the Council, and shall be confirmed at the ensuing general meeting by a majority consisting of three-fourths of the Members present and voting.

Council.

10. The Society shall be governed by a Council, consisting of a President, two Vice-Presidents, a General Secretary, a Foreign Secretary, a Treasurer, an Editor of the Journal, and twelve Ordinary Members.

11. All members of the Society who have served the office of President shall be life-members of the Council.

11 *a*. The Trustees of the Society shall be *ex officio* members of the Council.

12. The Council shall be elected annually at the Anniversary Meeting.

13. Four Ordinary Members of Council shall retire annually, and shall not be eligible for re-election until the next Anniversary Meeting.

14. The Council shall prepare a list of Members nominated for election as Officers and Ordinary Members of Council.

15. The election of Council shall be effected by the agency of voting papers containing the List nominated by the Council. They shall be sent by the General Secretary, at least four weeks before the Anniversary Meeting, to every Ordinary Member of the Society, and every such Member shall be entitled to substitute the names of any other Ordinary Members of the Society for those on the List.

16. The voting papers shall be returned by the Members to the General Secretary, and shall be examined at the Anniversary Meeting by two Scrutineers appointed by the Chairman, who shall on their report declare the result of the election. The voting papers need not be signed.

17. The Council shall have power to appoint Officers, and to co-opt Ordinary Members of Council, to fill vacancies in the Council caused

by death or resignation during the interval between two Anniversary Meetings.

18. Meetings of the Council shall be summoned by order of the President or the Council; at such meetings three shall be a quorum, of whom one shall be either the President, a Vice-President, the Treasurer, or the General Secretary.

19. A Report of Council on the work and progress of the Society shall be submitted to each Anniversary Meeting.

Trustees.

20. Two or more Trustees shall be appointed by the Council, and the invested property of the Society shall stand in their names.

21. Composition-fees shall be treated as Capital: a Resolution of the Society at a general meeting, summoned with notice of a proposed disposition of property, shall be sufficient authority to the Trustees to give effect to such disposition; provided that a resolution of the Council shall be sufficient authority for any change of investment.

Meetings.

22. Meetings of the Society shall be summoned from time to time as may be deemed necessary by the Council, or at the requisition of any ten Members of the Society. One of these meetings in each year shall be termed the Anniversary Meeting.

Journal.

23. The Numbers of the *Mineralogical Magazine and Journal of the Society* shall be issued at such intervals as the Council shall determine, and shall be sent, postage paid, to every Member of the Society.

Auditors and Balance Sheet.

24. Two Ordinary Members of the Society, one of whom is not a Member of the Council, shall be appointed annually by the Council to audit the accounts of the Society.

25. No auditor shall serve for more than three years in succession.

26. The audited Balance Sheet, after submission to the Council, shall be published in the Journal of the Society as early as possible in every year.

Expulsion of Members.

27. A majority consisting of three-fourths of the whole Council shall have power to expel a Member from the Society, but a Member who has been expelled shall have a right of appeal to the Society. Notice of such appeal to the Society shall be sent by such Member to the General Secretary within four weeks of the expulsion, and the appeal shall be considered by the Society at the next Anniversary Meeting; a majority of the votes recorded at such Meeting sufficing to confirm or annul the decision of the Council.

Alteration of the Bye-Laws.

28. The Bye-laws may be altered only at an Anniversary Meeting, and only by a majority consisting of three-fourths of the Members present and voting. Notice of changes proposed to be made in the Bye-laws shall be communicated by the General Secretary to every Ordinary Member of the Society at least four weeks before the Anniversary Meeting at which they are to be considered.

Obligation Book.

29. Ordinary Members, by payment of their entrance fee, signify their acceptance of any Bye-laws approved by the Society; and every Member of the Society shall sign an Obligation Book.

LIST OF MEMBERS

(*February*, 1929)

HONORARY MEMBERS

Year of Election.

1909 Becke, Friedrich Johann. Emeritus Professor of Mineralogy and Petrography in the University of *Vienna, Austria.*

1926 Brauns, Reinhard, Professor of Mineralogy and Petrography in the University of Bonn, *Endenicher-Alle, Bonn, Germany.*

1895 Brögger, Waldemar Christofer. *The University, Oslo, Norway.*

1909 Cesàro, Giuseppe. Emeritus Professor of Mineralogy in the University of *Liége, Belgium.*

1913 Clarke, Frank Wigglesworth. 5915 *Western Avenue, Chevy Chase, Washington, D.C., U.S.A.*

1897 Dana, Edward Salisbury. Yale University, *New Haven, Connecticut, U.S.A.*

1926 Duparc, Louis. Professor of Mineralogy, Petrography, and Analytical Chemistry, *École de Chimie, Université de Genéve, Switzerland.*

1912 Goldschmidt, Victor. Professor of Mineralogy in the University of Heidelberg. 9 *Gaisbergstrasse, Heidelberg, Germany.*

1900 Lacroix, Antoine François Alfred. Professor of Mineralogy in the Muséum National d'Histoire Naturelle. 61 *Rue de Buffon, Paris, V, France.*

1926 Rinne, Friedrich. Honorary Professor in the University of Freiburg, Baden. *Rehhagweg* 21, *Günterstal, Freiburg im Breisgau, Germany.*

1913 Wallerant, Frédéric. Professor of Mineralogy in the University, *Laboratories à la Sorbonne, Paris, France.*

ORDINARY MEMBERS[1]

A Annual Subscribers.
L Life-Members.
C Belonged to the Crystallological Society at the time of the amalgamation of the two Societies, December 11, 1883.

Year of Election.

A 1928 Anderson, Basil William, B.Sc., F.C.S. *'Thatched Cottage', Farleigh Common, Whyteleafe, Surrey.*

L 1926 Andrew, Gerald, M.Sc., F.G.S. *c/o Dept. of Geology, Egyptian University of Cairo, Egypt.*

A 1922 Arkell, Daniel John, B.Sc. *St. Edmund's College, Old Hall, Ware, Herts.*

L 1900 Ashcroft, Frederick Noel, M.A., F.C.S., F.G.S., F.R.G.S. 1 *Egerton Gardens, South Kensington, London, S.W.* 3.

A 1881 Baker, Harry, F.I.C., F.C.S. *'Beacon Field', Weston Road, Runcorn, Cheshire.*

A 1922 Balsillie, David, B.Sc., F.G.S., F.R.S.E. *Geological Dept., Royal Scottish Museum, Edinburgh.*

A 1927 Bannister, Frederick Allan, M.A. *Mineral Dept., British Museum (Natural History), South Kensington, London, S.W.* 7 ; and 29 *Waddon Court Road, Croydon, Surrey.*

A 1904 Barker, Thomas Vipond, M.A., D.Sc., F.C.S. *Dept. of Mineralogy, University Museum, Oxford;* and 329 *Woodstock Road, Oxford.*

L 1894 Barlow, William, F.R.S. *'Elm House', Stanmore, Middlesex.*

A 1913 Barreto, Dr. Antonio de Barros. Professor of Mineralogy and Geology in the Polytechnic School of São Paulo. *Rua Maranhão* 60, *Hygienopolis, São Paulo, Brazil.*

L 1893 Barrow, George, F.G.S., M.I.M.M. Formerly of the Geological Survey of Great Britain. 202 *Brecknock Road, London, N.* 19.

A 1928 Beard, Edward Harold, B.Sc. *Mineral Resources Dept., Imperial Institute, South Kensington, London, S.W.* 7 ; and 1 *Dolcoath Road, Camborne, Cornwall.*

[1] Corrections for this List should be sent to the General Secretary.

Year of Election.

A 1922 Belaiew, Nicholas Timothy, Colonel, C.B., F.C.S., M.I.M.E. 33 *Elvaston Place, Queen's Gate, London, S.W.* 7.

L 1912 Bell, Robert. 64 *Newington Avenue, Belfast.*

L 1888 Bemrose, Henry Howe, J.P., M.A., Sc.D., F.G.S. *Ash Tree House, Osmaston Road, Derby.*

A 1906 Blake, George Stanfield, B.Sc., A.R.S.M., F.G.S. Geological Survey of Palestine. *P.O. Box* 356, *Jerusalem, Palestine.*

A 1923 Blumenthal, Maurice. 558 *Quincy Street, Brooklyn, New York, U.S.A.*

A 1922 Boswell, Percy George Hamnall, O.B.E., D.Sc., A.R.C.S., F.G.S. Professor of Geology, The University, Liverpool. '*Alsager*', *Lyndhurst Road, Wallasey, Cheshire.*

A 1927 Boubée, Nérée, Licencié-ès-Sciences. 3 *Place St. André-des-Arts, Paris* 6^{e}, *France.*

L 1927 Bowen, Norman Levi, M.A., B.Sc., Ph.D., *Geophysical Laboratory,* 2801 *Upton Street, Washington, D.C., U.S.A.*

L 1897 Bowman, Herbert Lister, M.A., D.Sc., F.G.S., F.C.S. Professor of Mineralogy in the University of Oxford. *Dept. of Mineralogy, University Museum, Oxford.*

A 1923 Brady, Oscar Lisle, B.A., D.Sc., D.I.C., F.I.C., F.C.S., Reader in Organic Chemistry, University of London, University College. 5 *Woodside Avenue, Beaconsfield, Bucks.*

A 1923 Bragg, Sir Willian Henry, K.B.E., M.A., D.Sc., F.R.S. Director of the Royal Institution. 21 *Albemarle Street, London, W.* 1.

A 1920 Bragg, William Lawrence, O.B.E., M.A., F.R.S. Professor of Physics. *The University, Manchester.*

A 1919 Brammall, Alfred, Ph.D., M.Sc., D.I.C., F.G.S., A.I.M.M. *Dept. of Geology, Imperial College of Science and Technology, South Kensington, London, S.W.* 7.

A 1922 Broadhead, James. 15 *Langholm Crescent, Darlington, Co. Durham,*

	Year of Election.	
A	1923	Buckley, Harold Eugene, M.Sc. Lecturer in Crystallography, University of Manchester. '*Bradda*', *Hazelhurst Road, Worsley, Lancashire.*
A	1921	Bull, Alfred Joseph, M.Sc., F.Inst.P., F.G.S. *L.C.C. School of Photo-engraving,* 6 *Bolt Court, Fleet Street, London, E.C.* 4.
A	1926	Burri, Conrad Robert, Ph.D. *Mineralogical Institute, Sonneggstrasse* 5, *Zürich* 6, *Switzerland.*
L	1885	Butler, Francis Henry, M.A., A.R.S.M., L.S.A. (Lond.). 11 *Alfred Road, Sutton, Surrey.*
A	1919	Buttgenbach, Henri Jean François. Professor of Crystallography and Mineralogy in the University of Liége. 439 *Avenue Louise, Bruxelles, Belgium.*
A	1923	Cahn, Lazard. 6 *North Eighth Street, Colorado Springs, Colorado, U.S.A.*
A	1924	Campbell, Robert, M.A., D.Sc., F.G.S., F.R.S.E. Lecturer in Petrology, University of Edinburgh. '*Maryton*' *Woodhall Road, Colinton, Edinburgh.*
A	1928	Clarke, Edward de Courcy, M.A., A.I.M.M. *Dept. of Geology, University of Western Australia, Perth, Western Australia.*
L	1927	Clegg, Edward Leslie Gilbert, B.Sc. Assistant Superintendent, *Geological Survey of India,* 27 *Chowringhee Road, Calcutta, India.*
L	1927	Coke, Basil Elmsley, Lieut-Colonel R.E. (retired), O.B.E., M.A. '*The Hollies*', *Stafford.*
A	1913	Collingridge, Harvey, B.Sc., F.G.S., A.M.I.C.E. *Premier House,* 150 *Southampton Row, London, W.C.* 1.
L	1923	Combe, Arthur Delmar, F.G.S. *Geological Survey, Entebbe, Uganda, East Africa.*
L	1900	Coomaraswamy, Ananda K., D.Sc., F.L.S., F.G.S., M.R.A.S. Keeper of Indian Art, *Museum of Fine Arts, Boston, Mass., U.S.A.*
A	1924	Coussmaker, Arthur Blakeney, M.C., F.G.S., A.I.M.M. 78 *Hatton Garden, London, E.C.* 1.

Year of Election.

A 1907 Crook, Thomas, A.R.C.Sc.I., F.G.S. *Mineral Resources Dept., Imperial Institute, South Kensington, London, S.W.* 7.

L 1899 Cullis, Charles Gilbert, D.Sc., F.G.S., M.I.M.M. Professor of Economic Mineralogy, *Imperial College of Science and Technology, South Kensington, London, S.W.* 7.

L 1899 Currie, James, M.A., F.R.S.E. *'Larkfield', Golden Acre, Edinburgh.*

A 1926 Davies, George MacDonald, M.Sc., F.G.S. Lecturer in Geology, Birkbeck College, London. 104 *Avondale Road, South Croydon, Surrey.*

L 1885 Daw, John Williams, M.I.M.M. *Axim, Gold Coast Colony, West Africa.*

L 1898 De Castro, John Paul, M.A., F.C.S., F.I.C. 10 *Nevill's Court, Fetter Lane, London, E.C.* 4.

A 1925 Dewey, Henry, F.G.S. Geological Survey of Great Britain, 28 *Jermyn Street, London, S.W.* 1.

A 1925 Double, Ivan Sidney, M.Sc., F.G.S. *Geological Dept., The University, Liverpool.*

A 1928 Douglas, George Vibert, M.Sc., B.Sc. 35 *Bella Vista, Minas de Rio Tinto, Huelva, Spain;* and *Royal Societies Club,* 63 *St. James Street, London, S.W.* 1.

L 1910 Drugman, Julien Léon Eugène, Ph.D., M.Sc. 33 *Rue Edmond Picard, Uccle, Brabant, Belgium.*

A 1925 Dwerryhouse, Arthur Richard, T.D., D.Sc., F.G.S., M.R.I.A. 16 *Darell Road, Caversham, Oxfordshire.*

L 1926 Eckermann, Harry von, Ph.D. *Edeby pr Sparreholm, Sweden.*

L 1918 Edge, Arthur Broughton, M.B.E., A.R.S.M., A.R.C.S., B.Sc., F.C.S., F.G.S. *c/o Royal School of Mines, South Kensington, London,S.W.* 7.

A 1927 Elles, Miss Gertrude Lilian, M.B.E., D.Sc. *Newnham College, Cambridge.*

A 1925 Ellsworth, Hardy Vincent, M.A., Ph.D. *Geological Survey of Canada, Ottawa, Canada.*

	Year of Election.	
A	1919	ELSDEN, James Vincent, D.Sc., F.G.S. 14 *St. Saviour's Road, St. Leonards-on-Sea, Sussex.*
A	1920	ENGLISH, George Letchworth. 50 *Brighton Street, Rochester, New York, U.S.A.*
L	1891	EVANS, John William, C.B.E., LL.B., D.Sc., F.R.S. 121 *Harley Street, London, W.* 1.
A	1929	EYLES, Victor Ambrose, B.Sc. Geological Survey of Great Britain (Scottish Office), '*Southpark*', 19 *Grange Terrace, Edinburgh.*
A	1924	FABRY, Richard John Charles, A.R.C.S., B.Sc. *Geological Survey of Canada, Ottawa, Canada.*
L	1926	FEARNSIDES, William George, M.A., F.G.S. Professor of Geology, University of Sheffield. 11 *Ranmoor Crescent, Sheffield.*
A	1915	FERMOR, Lewis Leigh, O.B.E., A.R.S.M., D.Sc., F.G.S. Superintendent, *Geological Survey of India*, 27 *Chowringhee Road, Calcutta.*
L	1895	FLETCHER, Rev. Mark, M.A., M.Sc., F.G.S. Lecturer in Mineralogy in the Armstrong College, Newcastle-on-Tyne. *Long Benton Vicarage, Forest Hall, Northumberland.*
L	1902	FLETT, Sir John Smith, K.B.E., M.A., LL.D., D.Sc., F.R.S. Director of the Geological Survey of Great Britain. 28 *Jermyn Street, London, S.W.* 1.
A	1926	FORD, Hugh Alexander, H.B.M. Consul. *The British Consulate, Lyons, France.*
A	1923	GARNETT, Cecil Stevenson, F.C.S., F.G.S. 25 *Crompton Street, Derby.*
L	1886	GOLDSCHMIDT, Victor, Ph.D., Professor of Mineralogy in the University of Heidelberg. 9 *Gaisbergstrasse, Heidelberg, Germany.*
A	1905	GOODCHILD, Wilbert, M.B., Ch.B. *Blencathra Sanatorium, Threlkeld, Penrith, Cumberland.*
A	1922	GORDON, Hugh Septimus, M.I.M.M., F.G.S. 10 *Nevill's Court, Fetter Lane, London, E.C.* 4: and *Tati Company, Limited, Francistown, Bechuanaland Protectorate, South Africa.*

Year of Election.

A 1923 Gordon, Samuel George. *Academy of Natural Sciences, Logan Square, Philadelphia, Pennsylvania, U.S.A.*

A 1923 Gordon, William Thomas, M.A., D.Sc., F.R.S.E., F.G.S. Professor of Geology, *King's College, Strand, London, W.C.* 2.

A 1903 Grabham, George Walter, M.A., F.G.S. Geologist to the Sudan Government. *P.O. Box* 178, *Khartum, Sudan.*

A 1913 Graham, Richard Percival Devereux, B.A. Assistant Professor of Mineralogy, *McGill University, Montreal, Canada.*

A 1924 Grantham, Donald Robert, A.R.S.M., A.R.C.S., D.Sc., *Geological Survey Dept., Dodoma, Tanganyika Territory, East Africa.*

A 1923 Greenwood, Gilbert, M.Sc. *Thorn Bank, Edenfield, Manchester.*

A 1921 Gregory, Albert George Frederick. 30 *Church Street, Chelsea, London, S.W.* 3; and '*Hillside*', 21 *Rusholme Road, Putney Hill, London, S.W.* 16.

L 1892 Gregory, John Walter, D.Sc., LL.D., F.R.S. Professor of Geology, *University of Glasgow.*

A 1912 Hallimond, Arthur Francis, M.A., F.G.S. Assistant Curator, *Museum of Practical Geology*, 28 *Jermyn Street, London, S.W.* 1.

A 1885 Harker, Alfred, M.A., LL.D., F.R.S. University Reader in Petrology. *St. John's College, Cambridge.*

L 1900 Hartley, Sir Harold Brewer, Kt., M.C., C.B.E., M.A., F.R.S. *Balliol College, Oxford.*

A 1917 Harwood, Henry Francis, M.Sc., Ph.D., A.I.C., F.C.S. Lecturer in Chemistry, *Imperial College of Science and Technology, South Kensington, London, S.W.* 7.

A 1910 Hatch, Frederick Henry, O.B.E., Ph.D., M.I.M.M., F.G.S. *Mines Department, Dean Stanley Street, Westminster, London, S.W.* 1.

	Year of Election.	
A	1921	HAWKES, Leonard, D.Sc., F.G.S. Reader in Geology, University of London. *Bedford College, Regent's Park, London, N.W.* 1.
A	1928	HEIDE, Fritz, D.Ph. *Nikolausbergerweg* 59, *Göttingen, Germany.*
L	1879	HENSON, Samuel. c/o *Dr. James White, 'South House', Chislehurst, Kent.*
A	1929	HEY, Max Hutchinson, B.A., B.Sc. *Mineral Dept., British Museum (Natural History), South Kensington, London, S.W.* 7.
L	1907	HILTON, Harold, M.A., D.Sc. Professor of Mathematics in the University of London. *Bedford College, Regent's Park, London, N.W.* 1.
A	1927	HITCHEN, Charles Stansfield, B.Sc., A.R.C.S. 14 *Herondale Avenue, Wandsworth Common, London, S.W.* 18.
A	1928	HODGE, Matthew Burnop, M.Sc., Ph.D. *Dept. of Geology, The University, Manchester.*
L	1896	HOLLAND, Sir Thomas Henry, K.C.S.I., K.C.I.E., A.R.C.S., D.Sc., F.R.S. Rector of the Imperial College of Science and Technology. 6 *Wetherby Gardens, London, S.W.* 5.
A	1914	HOLMES, Arthur, D.Sc., D.I.C., A.R.C.S., F.G.S. Professor of Geology in the University of Durham. *Science Laboratories, South Road, Durham.*
A	1908	HOPKINS, Edward. 32–34 *Holborn Viaduct, London, E.C.* 1.
A	1925	HORN, Aubrey Evelyn, *Loup House, Axminster, Devon*; and *c/o Naraguta (Nigeria) Tin Mines, Ltd., P.O. Jos, Northern Nigeria.*
A	1902	HOWE, John Allen, O.B.E., B.Sc., F.G.S. Assistant to the Director, Geological Survey of Great Britain. 28 *Jermyn Street, London, S.W.* 1.
A	1928	HOWLING, Gerald Edward, B.Sc. *Mineral Resources Dept., Imperial Institute, South Kensington, London, S.W.* 7.

Year of Election.

L 1890 Hutchinson, Arthur, O.B.E., M.A., Ph.D., F.R.S. Professor of Mineralogy in the University of Cambridge, Master of *Pembroke College, Cambridge.*

A 1923 Jardine, Irvine George, B.Sc., F.G.S. 27 *Cecil Road, Upton Manor, London, E.* 13.

A 1920 Johnson, Edward Lionel, M.Sc., F.G.S. *Ashfield, Castleton, Yorkshire.*

A 1925 Johnston, Robert Angus Alister, F.R.C.S. *c/o The Bronson Company, Ottawa, Canada.*

L 1905 Jones, Bernard Mouat, D.S.O., M.A., F.C.S. Principal of *The College of Technology, Manchester.*

L 1908 Jones, Owen Thomas, M.A., D.Sc., F.R.S. Professor of Geology, *The University, Manchester.*

A 1929 Kennedy, William Quarrier, B.Sc., Ph.D. Geological Survey of Great Britain (Scottish Office). '*Southpark*', 19 *Grange Terrace, Edinburgh.*

A 1917 Kitson, Sir Albert Ernest, C.M.G., C.B.E., F.G.S. Director of the Geological Survey of the Gold Coast. 75 *Cornwall Gardens, South Kensington, London, S.W.* 7.

A 1926 Kreutz, Stefan, Ph.D. Professor of Mineralogy and Crystallography in the University of Kraków. *Collegium Minus, Gołębia* 11, *Kraków, Poland.*

L 1926 Krishnan, Maharajapuram Sitaram, M.A., Ph.D., A.R.C.S., D.I.C. Assistant Superintendent, *Geological Survey of India,* 27 *Chowringhee Road, Calcutta, India.*

A 1885 Kunz, George Frederick, M.A., Ph.D., Sc.D., F.G.S. 405 *Fifth Avenue, New York City, U.S.A.*

A 1922 Lake, Harry William, Colonel, C.M.G., M.I.M.M. 26 *Bolton Gardens, London, S.W.* 5; and 5 *Broad Street Avenue, Blomfield Street, London, E.C.* 2.

A 1924 Lane, Alfred Church, A.B., Ph.D., Sc.D. Professor of Geology, *Tufts College, Massachusetts, U.S.A.*

A 1923 Larsen, Esper Signius, Ph.D. Professor of Petrology. *Harvard University, Cambridge, Massachusetts, U.S.A.*

A 1923 Leech, John George Chambré, A.R.S.M. 7 *Belvedere Grove, Wimbledon, London, S.W.* 19.

	Year of Election.	
A	1879	Louis, Henry, M.A., D.Sc., A.R.S.M., F.G.S. Emeritus Professor of Mining in the Armstrong College, University of Durham. 4 *Osborn Terrace, Jesmond, Newcastle-upon-Tyne.*
A	1925	Lumb, Arthur Douglas, M.C., A.R.S.M., F.G.S., M.I.M.M., F.R.G.S. *Heathcote, Fair Oak Lane, Oxshott, Surrey.*
A	1914	Macgregor, Alexander Miers, B.A., F.G.S. Geological Survey of Southern Rhodesia. *P.O. Box* 366, *Salisbury, Rhodesia.*
A	1929	MacGregor, Archibald Gordon, M.C., B.Sc. Geological Survey of Great Britain (Scottish Office), '*Southpark*', 19 *Grange Terrace, Edinburgh.*
A	1929	Macgregor, Murray, M.A., B.Sc., F.R.S.E. Geological Survey of Great Britain (Scottish Office), '*Southpark*', 19 *Grange Terrace, Edinburgh.*
A	1925	Maclaren, James Malcolm, D.Sc., F.G.S. '*Burncoose*', *Gwennap, Redruth, Cornwall*; and *Royal Colonial Institute, Northumberland Avenue, London, S.W.* 1.
A	1908	McLintock, William Francis Porter, D.Sc., F.G.S. Curator of the *Museum of Practical Geology*, 28 *Jermyn Street, S.W.* 1.
A	1921	McRobert, Lady Rachel Workman, B.Sc., F.G.S. '*Douneside*', *Tarland, Aboyne, Aberdeenshire.*
A	1925	Marshall, Patrick, M.A., D.Sc., F.G.S. '*Hautere*', *Bellevue Road, Lower Hutt, Wellington, New Zealand.*
A	1927	Mathews, Charles William, F.G.S. 14 *Hatton Garden, London, E.C.* 1.
L	1919	Melmore, Sidney, B.Sc., F.G.S. '*Winkinghurst*', *Carr Lane, Acomb, York.*
A	1923	Merwin, Herbert Eugene, Ph.D. *Geophysical Laboratory*, 2801 *Upton Street, Washington, D.C., U.S.A.*
L	C	Miers, Sir Henry Alexander, Kt., M.A., D.Sc., LL.D., F.R.S. Honorary Professor of Crystallography in the University of Manchester. 18 *Aberdare Gardens, West Hampstead, London, N.W.* 6.

	Year of Election.	
A	1923	Milner, Henry Brewer, M.A., F.G.S. 4 *Wycombe Gardens, Golders Green, London, N.W.* 11.
A	1921	Mitchell, Allan Ernest, Ph.D., B.Sc., F.C.S. '*The Hollies*', *Norton-on-Tees, Co. Durham.*
A	1912	Morgan, Arthur Henry, A.M.I.C.E., M.I.M.M. Superintendent of the *Ruby Mines, Mogok, Upper Burma.*
L	1922	Mountain, Edgar Donald, M.A. *Rhodes University College, Grahamstown, South Africa.*
A	1924	Murray-Hughes, Robert, F.G.S. *The Standard Bank of South Africa,* 10 *Clement's Lane, London, E.C.* 3.
A	1927	Ogura, Tsutoma, Professor of Geology, *Ryojun College of Engineering, Port Arthur, Manchuria.*
L	1920	Ōhashi, Ryōichi. Professor of Geology and Mineralogy, *Akita Mining College, Akita, Japan.*
A	1926	Palache, Charles. Professor of Mineralogy, *Harvard University, Cambridge, Massachusetts, U.S.A.*
A	1922	Parker, Robert Luling, Ph.D. *Mineralogical Institute, Sonneggstrasse* 5, *Zürich* 6, *Switzerland.*
A	1915	Parsons, Arthur Leonard. Assistant-Professor of Mineralogy, *University of Toronto, Canada.*
A	1923	Phemister, James, M.A., B.Sc., F.G.S. Geological Survey of Great Britain (Scottish Office), '*Southpark*', 19 *Grange Terrace, Edinburgh.*
A	1926	Phemister, Thomas Crawford, Sc.M., Ph.D. *Dept. of Geology, University of British Columbia, Vancouver, British Columbia, Canada.*
A	1926	Phillips, Frank Coles, M.A., Ph.D., F.G.S. *Corpus Christi College, Cambridge.*
A	1922	Pillai, Cumbakonam Kailasa Krishnaswami, M.A. Professor of Geology, *Presidency College, Madras, India.*
L	1899	Pollard, William, M.A., D.Sc., F.G.S., F.C.S. '*Whitmore*', *Chittlehamholt, Umberleigh, North Devon.*
A	1891	Pope, Sir William Jackson, K.B.E., M.A., M.Sc., D.Sc., LL.D., F.R.S. Professor of Chemistry in the University of Cambridge. '*Holmleigh*', *West Road, Cambridge.*

	Year of Election.	
A	1910	PORTER, Miss Mary Winearls, B.Sc. 118 *Southmoor Road, Oxford.*
L	1887	PRIOR, George Thurland, M.A., D.Sc., F.R.S. Formerly Keeper of Minerals in the British Museum. '*Millholm*', *Pinner Hill, Pinner, Middlesex.*
A	1922	PUCKLE, Geoffrey Montagu. *Swallowfield Park, Reading, Berks.*
L	1908	RAISIN, Miss Catherine Alice, D.Sc., F.L.S., F.G.S. 62 *Redcliffe Gardens, London, S.W.* 10.
A	1903	RASTALL, Robert Heron, M.A., Sc.D., F.G.S., M.I.M.M. *Christ's College, Cambridge.*
A	1923	READ, Herbert Harold, D.Sc., A.R.C.S., F.G.S. Geological Survey of Great Britain (Scottish Office), '*Southpark*', 19 *Grange Terrace, Edinburgh.*
A	1922	REEKIE, John, B.A. *Burnham, Brooklands, Broxbourne, Herts.*
A	1915	RICHARDSON, William Alfred, D.Sc., B.A., B.Sc. (Engin.), F.G.S. Principal of the Newark School of Science and Art, *London Road, Newark-on-Trent.*
A	1929	RICHEY, James Ernest, M.C., B.A., F.R.S.E., F.G.S. Geological Survey of Great Britain (Scottish Office), '*Southpark*', 19 *Grange Terrace, Edinburgh.*
A	1919	ROBERTS, Malcolm, A.R.S.M., M.I.M.M, *c/o The Bolivian Legation*, 16 *Grosvenor Place, London, S.W.* 1.
A	1914	ROGERS, Arthur William, M.A., Sc.D., F.R.S. Director of the Geological Survey of the Union of South Africa, *P.O. Box* 401, *Pretoria, Transvaal, South Africa.*
A	1913	ROGERS, Austin Flint, A.M., Ph.D. Professor of Mineralogy and Petrography, *Leland Stanford Junior University, Palo Alto, California, U.S.A.*
A	1902	RUSSELL, Arthur Edward Ian Montagu, M.B.E. *Swallowfield Park, Reading, Berks.*
A	1918	SANDISON, William Greswolde Williams. *Kilda, Baltasound, Unst, Shetland.*

Year of Election.

A 1912 Schaller, Waldemar Theodore, Ph.D. *United States Geological Survey, Washington, D.C., U.S.A.*

A 1919 Schoeller, Walter Raymond, Ph.D., A.I.M.M., A.I.C. *'Purbeck', Great Missenden, Bucks.*

A 1920 Schoep, Alfred, D.Sc. Professor of Crystallography and Mineralogy in the University of Ghent, 6 *Rue de la Roseraire, Ghent, Belgium.*

A 1928 Scholtz, Douglas Leinster, M.Sc. Lecturer in Geology, *Transvaal University College, Pretoria, Transvaal, South Africa.*

A 1914 Scott, Alexander, M.A., D.Sc. *Pottery Laboratory, Central School of Science and Technology, Stoke-on-Trent, Staffordshire.*

A 1908 Shand, Samuel James, D.Sc., Ph.D., F.G.S. Professor of Geology, *University of Stellenbosch, South Africa.*

A 1919 Sheppard, George, D.Sc., F.G.S. 3 *Village Road, Garden Village, Hull, Yorkshire*; and *Casilla* 140, *Guayaquil, Ecuador.*

A 1912 Simpson, Edward Sydney, D.Sc., B.E., F.C.S. Government Mineralogist and Chemist, Western Australia. *'Carlingford', Mill Point, South Perth, Western Australia.*

L 1897 Smith, George Frederick Herbert, M.A., D.Sc., F.G.S., F.R.A.S. *British Museum (Natural History), South Kensington, London, S.W.* 7.

A 1911 Smith, Herbert Gladstone, B.Sc., A.R.C.S., F.G.S. Reader in Geology in the University of London, *East London College, Mile End Road, London, E.* 1.

L 1910 Smith, Walter Campbell, M.C., M.A., F.G.S. *Mineral Dept., British Museum (Natural History), South Kensington, London, S.W.* 7.

A 1928 Sneesby, George William, B.Sc. *'Unicorn Cottage', Wilburton, Isle of Ely.*

A 1925 Spencer, Edmondson, Ph.D., B.Sc., A.R.S.M., F.I.C., F.G.S. *c/o Messrs. Bird & Co. (Research Dept.), Post Box* 46, *Calcutta, India.*

Year of Election.

A 1894 Spencer, Leonard James, M.A., Sc.D., F.R.S. Keeper of Minerals in the British Museum, *Mineral Dept., British Museum* (*Natural History*), *South Kensington, London, S.W.* 7.

A 1928 Spiller, Reginald Charles, M.A. Demonstrator in Mineralogy, *Dept. of Mineralogy, University Museum, Oxford.*

A 1923 Stillwell, Frank Leslie, D.Sc. 44 *Elphin Grove, Hawthorne, Victoria, Australia.*

A 1923 Stockley, Gordon Murray, A.R.C.S., A.I.C., F.C.S., F.G.S. *Geological Survey Dept., Dodoma, Tanganyika Territory, East Africa.*

A 1927 Storr, William Richard. 17 *Christchurch Gardens, Reading, Berks.*

A 1926 Stuart, Alan, M.Sc., F.G.S. '*Bungalow*', *Bayswater Road, Sketty, Swansea.*

A 1928 Sweet, Miss Jessie May, B.Sc. *Mineral Dept., British Museum* (*Natural History*), *South Kensington, London, S.W.* 7.

A 1925 Swinton, William Elgin, B.Sc., F.G.S., F.L.S., F.Z.S. *Geological Dept., British Museum* (*Natural History*), *South Kensington, London, S.W.* 7.

A 1925 Tarr, William Arthur, B.Sc., B.S., Ph.D. Professor of Geology and Mineralogy, *University of Missouri*; and 704 *Westwood Avenue, Columbia, Missouri, U.S.A.*

A 1922 Taylor, Joseph Cornelius. '*Rodmersham*', 7 *Albert Road, Hendon, London, N.W.* 4.

A 1903 Thomas, Herbert Henry, M.A., Sc.D., F.R.S. Petrographer to the Geological Survey of Great Britain. 28 *Jermyn Street, London, S.W.* 1.

A 1925 Thomson, Ellis, B.A.Sc. Assistant-Professor, *Dept. of Mineralogy, University of Toronto, Canada.*

A 1921 Tilley, Cecil Edgar, B.Sc., Ph.D., A.I.C., F.G.S. *Sedgwick Museum, Cambridge.*

A 1925 Tomkeieff, Sergei Ivanovich, F.G.S. *Geology Dept., Armstrong College, Newcastle-upon-Tyne.*

	Year of Election.	
L	1927	Trechmann, Charles Taylor, D.Sc., F.G.S., F.Z.S. '*Hudworth Tower*', *Castle Eden, Co. Durham.*
A	1923	Tsuboi, Seitarō. *Geological Institute, College of Science, Imperial University, Tokyo, Japan.*
L	1920	Tunbridge, Edward William, B.Sc., F.G.S. '*Westbury*', *Lillington, Leamington Spa, Warwickshire.*
L	1891	Tutton, Alfred Edwin Howard, M.A., D.Sc., F.R.S. '*Silbury*', 60 *Grange Road, Cambridge.*
A	1925	Vendl, Aladár, Ph.D. Professor in the Technical High School, *Rezeda utca* 7, *Budapest I, Hungary.*
A	1925	Vendl, Miklós, Ph.D. Professor of Mineralogy and Geology, *Mining Academy, Sopron, Hungary.*
A	1913	Walker, Thomas Leonard, M.A., Ph.D., F.G.S. Director of the Royal Ontario Museum of Mineralogy, and Professor of Mineralogy and Petrography in the *University of Toronto, Canada.*
A	1923	Washington, Henry Stephens, Ph.D. *Geophysical Laboratory*, 2801 *Upton Street, Washington, D.C., U.S.A.*
A	1923	Watson, John Adam, A.C.G.I., F.I.C., F.C.S. 22 *Polwarth Gardens, Edinburgh.*
L	1894	Watts, William Whitehead, M.A., M.Sc., Sc.D., LL.D., F.R.S. Professor of Geology in the *Imperial College of Science and Technology, South Kensington, London, S.W.* 7.
A	1929	Weber, Leonhard, Ph.D. Professor of Mineralogy in the University, *Institut de Minéralogie, Université, Fribourg, Switzerland.*
L	1901	Weston, Digby St. Aubyn Percy, Commander, Royal Navy (retired). 79 *Onslow Gardens, London, S.W.* 7.
A	1924	Whitlock, Herbert Parry. *American Museum of Natural History, Central Park, New York City, U.S.A.*
A	1918	Wilcockson, William Howson, M.A., F.G.S. *Geological Dept., University of Sheffield.*
L	1925	Williams, Alpheus Fuller, B.Sc. General Manager, De Beers Consolidated Mines, Ltd., *P.O. Box* 616, *Kimberley, South Africa.*

	Year of Election.	
A	1918	WILLIAMS, Arthur Stanley, M.I.M.M. '*Ellerslie*', 4 *Russel Avenue, Hartley, Plymouth.*
L	1876	WILLS, Joseph Lainson. *Chemists Buildings*, 50 *East* 41*st Street, New York City, U.S.A.*
A	1923	WILSON, Norman Wrigley. *c/o John Perry, Esq.*, '*Halabe Zack*', *Carn Menellis, Redruth, Cornwall.*
L	C	WOODWARD, Charles Josiah, B.Sc., F.G.S. '*The Lindens*', *St. Mary's Road, Harborne, Birmingham.*
A	1927	WOOLDRIDGE, Sidney William, M.Sc., F.G.S. 46 *Hollingbourne Road, Herne Hill, London, S.E.* 24.
A	1927	WOOSTER, William Alfred, M.A., Ph.D. Demonstrator in Mineralogy in the University of Cambridge. *Peterhouse, Cambridge.*
A	1919	WORTH, Richard Hansford, M.Inst.C.E., F.G.S. 32 *Thornhill Road, Plymouth.*
L	1923	WRIGHT, Frederic Eugene, Ph.D. *Geophysical Laboratory*, 2801 *Upton Street, Washington, D.C., U.S.A.*
A	1921	ZUTSHI, Lambodhar, B.Sc. *c/o Lloyd's Bank, Srinagar, Kashmir, India.*

PROCEEDINGS
OF THE
MINERALOGICAL SOCIETY

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 17, 1928, *at* 4.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

The deaths of Prof. Paul H. von Groth, an Honorary Member since 1877, and of Mr. George Vaux, junior, were reported.

Mr. Edward de Courcy Clarke and Mr. Gerald Edward Howling were provisionally elected Ordinary Members of the Society.

In the absence of the Foreign Secretary, it was agreed that the President should send letters of congratulation to the Société française de Minéralogie on the occasion of its fiftieth anniversary, and to Prof. Victor Goldschmidt, of Heidelberg, on his seventy-fifth birthday.

The audited accounts and balance-sheet for the year ending December 31, 1927, were presented by the Treasurer and approved.

Resolved that if an annual subscriber is in arrears on December 31 no further issues of the Magazine shall be sent to him until the arrears have been paid.

Resolved that notices of meetings be posted to every member whose address is known, whether at home or abroad.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 17, 1928, *at* 5.30. *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty Members and seven Visitors were present.

The elections of Mr. E. de C. Clarke and Mr. G. E. Howling as Ordinary Members of the Society were confirmed.

The following papers were read :—

1. Potarite, a new mineral discovered by the late Sir John Harrison in British Guiana : by Dr. L. J. Spencer (vol. 21, p. 397).

2. A simple and accurate constant-volume pyknometer for specific gravity determinations: by Dr. H. V. Ellsworth (vol. 21, p. 431).

3. The optical orientation of labradorite from County Down (Ireland) determined by the Fedorov method: by Mr. W. Campbell Smith (vol. 21, p. 543).

Mr. A. F. Hallimond exhibited an electro-magnetic separator for mineral powders, and Dr. C. E. Tilley demonstrated the inversion of calcium orthosilicate in a metamorphic limestone from Larne, Co. Antrim.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 20, 1928, *at* 4.45 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Mr. Douglas Leinster Scholtz and Mr. Reginald Charles Spiller were provisionally elected Ordinary Members of the Society.

The name of Mr. F. Barbason was removed from the list of members for non-payment of subscriptions.

A letter from Prof. Victor Goldschmidt was read.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 20, 1928, *at* 5.30. *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty Members and twelve Visitors were present.

The elections of Mr. D. L. Scholtz and Mr. R. C. Spiller as Ordinary Members of the Society were confirmed.

The following papers were read:—

1. On the atomic volume relations in certain isomorphous series, II: by Mr. A. F. Hallimond (vol. 21, p. 480).

2. The age and composition of the Whin Sill and related dikes of the north of England: by Prof. A. Holmes and Dr. H. F. Harwood (vol. 21, p. 493).

3. The identification of dumortierite in grains; dumortierite in Cornish granite: by Mr. A. W. Groves (vol. 21, p. 489.)

4. On 'bauxite' from Kashmir: by Dr. T. V. M. Rao.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 12, 1928, *at* 4.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

The deaths of Mr. Benedict Kitto, one of the original members of the Society, and of Dr. John Horne, formerly a member, were reported.

Mr. Basil William Anderson, Dr. Fritz Heide, Mr. George William Sneesby, and Miss Jessie May Sweet were provisionally elected Ordinary Members of the Society.

The list of Council Members and Officers for the ensuing year was considered, Sir Thomas Holland, Vice-President, and Prof. P. G. H. Boswell, Mr. T. Crook, Dr. L. Hawkes, and Dr. H. H. Thomas being due to retire by seniority. The following were proposed: Dr. J. W. Evans as Vice-President (and to retain the office of Foreign Secretary); Mr. Harvey Collingridge and Prof. Arthur Holmes, as former Members of the Council, and Colonel N. T. Belaiew and Mr. H. Dewey, as new members.

It was decided to hold meetings in 1929 on the following dates: Tuesdays, January 15, March 19, June 11, November 5.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 12, 1928, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Thirty Members and four Visitors were present.

The elections of Mr. B. W. Anderson, Dr. F. Heide, Mr. G. W. Sneesby, and Miss J. M. Sweet as Ordinary Members of the Society were confirmed.

The following papers were read:—

1. Place-names of mineral-localities in central Europe: by Prof. F. Slavík and Dr. L. J. Spencer (vol. 21, p. 441).

2. Eleventh list of new mineral names: by Dr. L. J. Spencer (vol. 21, p. 556).

3. On the atomic volume relations in certain isomorphous series, III: by Mr. A. F. Hallimond (vol. 22, p. 70).

4. On the determination of the optic axial angle and crystal-forms from observations by the Becke method in thin sections: by Mr. H. Collingridge (vol. 21, p. 552).

5. A contribution to the petrology of the Whin Sill: by Mr. S. I. Tomkeieff.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 6, 1928, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Mr. Edward Harold Beard, Mr. George Vibert Douglas, and Mr. Matthew Burnop Hodge were provisionally elected Ordinary Members of the Society.

The resignation of Mr. D. A. MacAlister was accepted.

The Treasurer, in his report, gave an estimate of the balance expected at the end of the year, and he recommended that no application be made to the Royal Society for a publication grant next year.

The Editor reported that the stock of current numbers of the Magazine is now very low, and on his proposal it was decided to print 600 of future numbers, commencing with the first number of vol. 22 in March 1929.

A specimen page set up in new type, submited by the printer (University Press, Oxford), was approved for the next volume.

The Librarian applied for a grant of £10 for binding periodicals, and authority was given to the Treasurer to transfer this sum from the General Purposes Account to the Library Fund Account on January 1, 1929.

Mr. A. J. Bull and Mr. Henry Dewey were appointed auditors of the accounts for the year ending December 31, 1928.

The Annual Report of the Council, submitted by the Secretary, was read and approved.

GENERAL (ANNIVERSARY) MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 6, 1928, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty-four Members and six Visitors were present.

The President nominated Mr. J. Broadhead and Mr. G. E. Howling to act as scrutineers of the voting-papers for the election of Officers

and Council. The scrutineers reported that sixty-five voting-papers had been returned to the Secretary, and that the list as nominated by the Council was approved, namely :—

President. Dr. G. T. Prior, M.A., D.Sc., F.R.S.
Vice-Presidents. Sir John S. Flett, K.B.E., M.A., LL.D., D.Sc., F.R.S.
Dr. J. W. Evans, C.B.E., LL.B., D.Sc., F.R.S.
Treasurer. F. N. Ashcroft, M.A., F.G.S., F.C.S.
General Secretary. W. Campbell Smith, M.C., M.A., F.G.S.
Foreign Secretary. Dr. J. W. Evans, C.B.E., D.Sc., LL.B., F.R.S.
Editor of the Journal. Dr. L. J. Spencer, M.A., Sc.D., F.R.S.

Ordinary Members of Council.

Prof. H. L. Bowmam, M.A., D.Sc., F.G.S., F.C.S.
Prof. W. T. Gordon, M.A., D.Sc., F.R.S.E.
Dr. H. F. Harwood, M.Sc., Ph.D., A.I.C.
Dr. G. F. Herbert Smith, M.A., D.Sc., F.G.S.
A. J. Bull, M.Sc., F.Inst.P., F.G.S.
Prof. C. G. Cullis, D.Sc., F.G.S.
Prof. Harold Hilton, M.A., D.Sc.
Dr. W. P. F. McLintock, D.Sc., F.G.S.
Colonel N. T. Belaiew, C.B., F.C.S.
Harvey Collingridge, B.Sc., F.G.S.
Henry Dewey, F.G.S.
Prof. Arthur Holmes, D.Sc., F.G.S.

The elections of Messrs. E. H. Beard, G. V. Douglas, and M. B. Hodge as Ordinary Members of the Society were confirmed.

A vote of thanks to the Geological Society for the use of their rooms, proposed by Mr. Hopkins and seconded by Mr. Bull was carried.

The General Secretary then read the following

Annual Report of Council.

During the session 1927–8 four ordinary meetings have been held, by kind permission, in the apartments of the Geological Society, Burlington House, London, W., at which sixteen papers were read. At the meeting on January 17 Mr. A. F. Hallimond exhibited an electro-magnetic separator for mineral powders, and Dr. C. E. Tilley demonstrated an inversion of calcium orthosilicate in a metamorphic limestone.

Four numbers of the Journal of the Society (nos. 119–122) have been issued, containing sixteen papers and 591 abstracts, of which 397 have been supplied by the Editor himself. [*continued on p. xxxvi.*]

MINERALOGICAL

ABSTRACT OF RECEIPTS AND PAYMENTS

Receipts.	£ s. d.	£ s. d.
		GENERAL PUR-
By Balance brought forward from 1927—		
1. At Bankers:		
(*a*) Current Account	18 14 10	
(*b*) Deposit Account	140 0 0	
2. In Office	0 3 3	
		158 18 1
Annual Subscriptions—		
1. Current year	137 11 0	
2. Arrears	1 1 0	
3. Advance	6 15 0[1]	
		145 7 0
Entrance Fees		10 10 0
Composition Fees		26 5 0
Sale of Publications—		
1. By Publishers, April 1, 1927–March 31, 1928. Subscription Copies £196, and other sales £128 5*s.* 6*d.*, less trade discount and commission £91 15*s.* 2*d.*, and postage and packing £11 16*s.* 1*d.*	220 14 3	
2. By Custodian of Stock, 1928. £8 1*s.* 0*d.*, less trade discount (nil) and distribution charges 18*s.* 11*d.*	7 2 1	
		227 16 4
Advertisement Fees £19 8*s.* 10*d.*, less commission £3 17*s.* 9*d.*		15 11 1
Interest on Investments—		
1. £1,530 5% War Loan 1929–47 Inscribed Stock	75 17 6[2]	
2. £105 4% Consolidated Loan 1957 Inscribed Stock	4 4 0	
3. £50 4% Funding Loan 1960–90 Inscribed Stock	2 0 0	
		82 1 6
Deposit Interest		7 2 9
Small Receipts		0 1 6
		£673 13 3

[1] Includes a part payment.
[2] First half-year on £1,505 stock, second half-year on £1,530 stock.

SOCIETY

FOR THE YEAR ENDING DECEMBER 31, 1928

POSES ACCOUNT.

Payments.	£ s. d.	£ s. d.
To Printing and distributing the Mineralogical Magazine Nos. 120–123 inclusive (Oxford University Press)—		
1. Printing.	380 17 3	
2. Illustrations	9 18 3	
3. Authors' Copies	24 4 0	
4. Distribution Charges	12 18 0	
5. Extra type (special letters)	12 18 0	
6. Printed postal wrappers (renewal of stock) .	1 9 0	
		442 4 6
Printing and distributing notices of Meetings and other annual miscellaneous printing		16 0 0
Expenses at Meetings, 1928—		
1. Operator of lantern	1 1 0	
2. Porter	1 0 0	
		2 1 0
Care of Stock of Publications, 1928 (J. Mugford)		1 1 0
Editor's Honorarium, 1928		50 0 0
Stationery		0 16 6
Postage—		
1. Hon. Secretary	0 9 6	
2. Editor	2 0 0	
3. Hon. Treasurer (not charged) . . .		
		2 9 6
Bank charges and other small items		0 1 6
Investments, purchase of £25 5% War Loan, 1929–47 Inscribed Stock, commission and stamp		25 18 11[1]
Balance, December 31, 1928—		
1. At Bankers:		
(*a*) Current Account	7 11 6	
(*b*) Deposit Account	125 0 0	
2. In Office	0 8 10	
		133 0 4
		£673 13 3

Examined and compared with vouchers and found correct.

A. J. BULL
HENRY DEWEY } Auditors.

January 7, 1929.

F. N. ASHCROFT, Hon. Treasurer.

[1] A small portion of the sum received by way of Composition Fees during the year has still to be invested.

LIBRARY FUND

Receipts.	£	s.	d.
By Balance brought forward from 1927—			
At Bankers	6	19	0
	£6	19	0

BALANCE

DECEMBER

Liabilities.	£	s.	d.
Excess of Assets over Liabilities	1986	0	8
	£1986	0	8

ACCOUNT.

Payments.	£	s.	d.
To Binding of Periodicals	4	13	9
Balance, December 31, 1928—			
At Bankers	2	5	3
	£6	19	0

Examined and compared with vouchers and found correct.

A. J. BULL
HENRY DEWEY } Auditors.

January 7, 1929. F. N. ASHCROFT, Hon. Treasurer.

SHEET

31, 1928.

Assets.	£	s.	d.	£	s.	d.
Balances—						
I. General Purposes Account:						
1. At Bankers:						
(*a*) Current Account	7	11	6			
(*b*) Deposit Account	125	0	0			
2. In Office	0	8	10			
				133	0	4
II. Library Fund Account—						
At Bankers				2	5	3
Sale of Publications—						
1. By Publishers, April 1 to Dec. 31, 1928	106	5	1			
2. By custodian, 1928	15	11	6			
				121	16	7
Investments at Broker's Valuation—						
1. £1,530 5 % War Loan Inscribed Stock at 102¾	1572	1	6			
2. £50 4 % Funding Loan Inscribed Stock at 90	45	0	0			
3. £105 4 % Consolidated Loan Inscribed Stock at 87[1].	91	7	0			
				1708	8	6
Advertisement Fees				15	5	0
Arrears of Annual Subscriptions, valued at				5	5	0
				£1986	0	8

Neither the value of the Library nor that of the Stock of Publications are included in the above assets.

January 17, 1929. F. N. ASHCROFT, Hon. Treasurer.

[1] Ex dividend payable February 1, 1929.

The President, Dr. G. T. Prior, has continued to represent the Society on the Federal Council of Pure and Applied Chemistry.

The balance-sheet for the year ending December 31, 1927, showed assets (exclusive of the Library and stock of the publications) £1,961 19*s.* 7*d.*, with liabilities nil. The value of the stock invested in the names of the Trustees of the Society was on December 31, 1927, £1,657 19*s.* 6*d.*, equivalent to £32 10*s.* 2*d.* for each life-member. During the present session the sales of the Society's Journal show a satisfactory increase over those for 1926–7.

Ten new members have been elected, but the Society has lost one of its Honorary Members, Prof. Paul Heinrich von Groth, who died on December 2, 1927, and two Ordinary Members, George Vaux, junior, and Benedict Kitto. The latter, who died on May 13, 1928, was one of the original members of the Society. The name of one member has been removed from the Society's list for non-payment of subscriptions. This left the total membership on October 31 at 208, including eleven Honorary Members. Of the Ordinary Members fifty-two are life-members.

The Society is to be congratulated on the scientific activity of its members and the high standard of its publications.

On the motion of Mr. Hallimond, seconded by Mr. Dewey, the report was adopted.

The following papers were then read :—

1. The so-called 'thermokalite' and the existence of sodium bicarbonate as a mineral : by Mr. F. A. Bannister (p. 53).

2. The piezo-electric effect of diamond : by Dr. W. A. Wooster (p. 65).

A short communication on the structure of brookite was made by Mr. J. D. Bernal and Nora Martin (Mrs. Wooster) and illustrated by lantern slides.

Mr. F. N. Ashcroft exhibited minerals collected recently in Switzerland, together with photographs of the mineral localities.

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The tholeiite dikes of the north of England.[1]

(With Plates I and II.)

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[Read January 15, 1929.]

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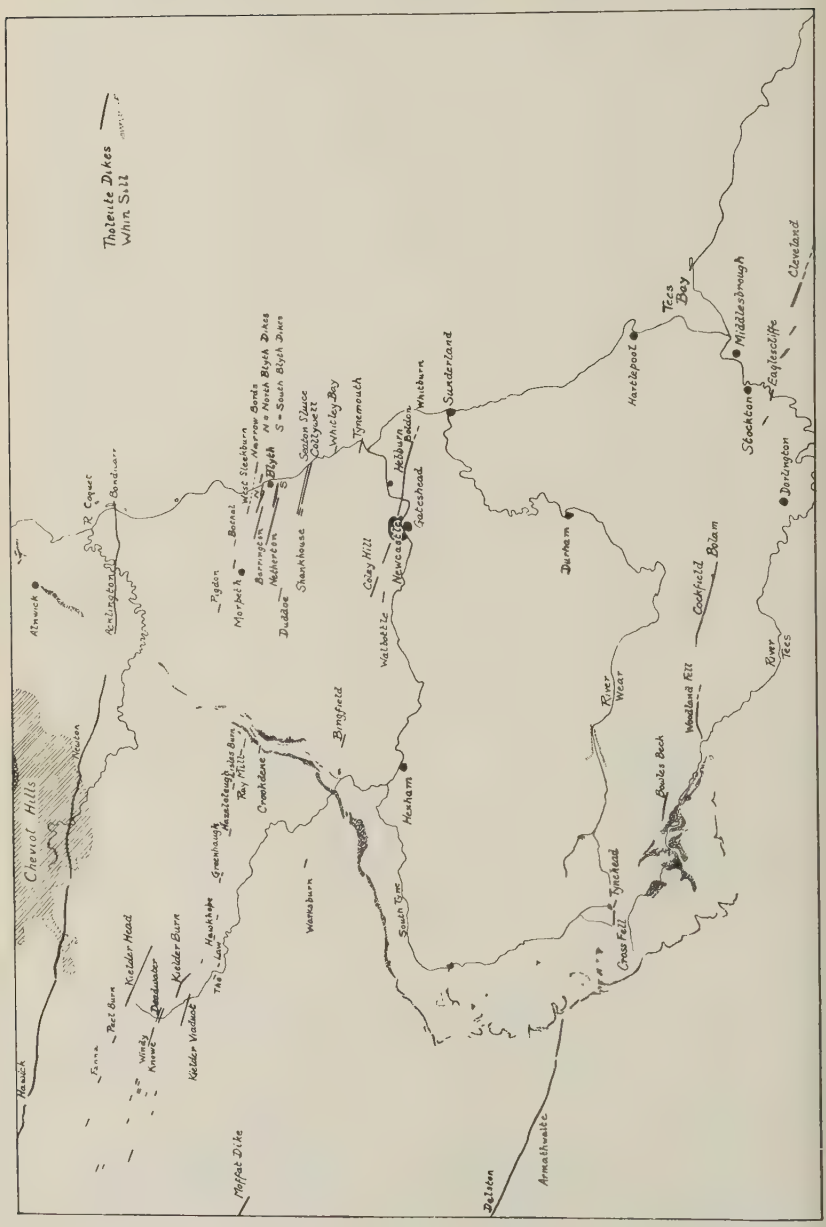
1. Introduction and Literature.

THE suite of dikes that forms the subject of this paper is bounded on the south from Sleights Moor (south of Whitby) to Dalston (south of Carlisle) by the well-known series of dikes known collectively as the Cleveland–Cockfield–Armathwaite dike, and on the north by the nearly parallel and more continuous Acklington dike which

[1] The eight new chemical analyses (and calculations of norms) presented in this paper have been made by Dr. Harwood. The field work and petrological investigations have been carried out by Professor Holmes, who is also responsible for the writing of the paper.


Tholeiite Dikes
Whin Sill
Cheviot Hills
Alnwick
Coquet R.
Bondicar
Rothbury
Pegdon
Morpeth
Bothal
West Sleekburn
Narrow Bonds
Blyth
N = North Blyth Dikes
S = South Blyth Dikes
Barrington
Meltonfen
Dudden
Shankhouse
Seaton Sluice
Earsdon
Whitley Bay
Tynemouth
Hebburn
Felling
Whitburn
Sunderland
Gateshead
Coxy Hill
Newcastle
Walbottle
Durham
Hartlepool
Tees Bay
Middlesbrough
Stockton
Eaglescliffe
Cleveland
Darlington
River Tees
Coxhoe
Coxfield
Bolam
Woodland Fell
Bowles Beck
River Wear
Tynehead
Cross Fell
Alston
Armathwaite
Hexham
South Tyne
Wansbeck
Bingfield
Crowhope
Rou Mill
Greenhaugh
Haughton
Tarset Burn
Kielder Burn
Kielder Head
Deadwater
Kielder Viaduct
Windy Knowe
Peel Burn
Fenna
Hawick
Moffat Dike
Jedburgh

stretches from Bondicarr near Coquet Island across the southern margin of the Cheviots into Scotland.

Between these boundary dikes lie several sets of shorter dikes all trending north of west. The distribution of the suite is shown in fig. 1, which is complementary to a similar sketch-map of the Whin Sill group of dikes presented in a former paper (**26**). As mapped in

Fig. 2. Map showing the relation of the tholeiite dikes of the north of England to the Mull swarm of dikes. [The Arran swarm dies out south-east of the Girvan–Ballentrae coast, where the dikes are more thickly distributed than is indicated on the map.]

the limited region of fig. 1, the dikes appear to converge towards a focus in the neighbourhood of Arran. To correct this impression, and to show the relations of the suite to the Tertiary dikes of the south and west of Scotland, fig. 2 has been compiled. This diagram clearly brings out a regional change of direction in the trend of the suite as it traverses the Southern Uplands, a change which carries the whole suite into the Mull swarm by way of Great Cumbrae and the coast of Ayrshire. The dikes of Bute do not appear to belong wholly to the suite we are considering, since they swing round in the south of the island towards the Arran focus. It is possible, however, that the tholeiites of Bute and Arran may be satellites from the Mull swarm. Dr. G. W. Tyrrell has pointed out to us that crinanitic types are dominant in the Arran swarm. No example of such types has

yet been found in the north of England. Thus, both distribution and petrological affinities lead to the interesting conclusion that the north of England tholeiite dikes represent an outlying extension of the Mull swarm.

As in the case of the Whin Sill and the late Carboniferous dikes, the pioneer investigation of the tholeiites was carried out by Teall (**2**). He described the Cleveland dike with great wealth of detail and recognized the close resemblance between many of its petrographic characters and those of the Acklington dike. Very little further work has since been done on the latter, but the Cleveland dike has received more attention, notably by Barrow in the district from which it takes its name (**6**); and by Miss Heslop and the late R. C. Burton, who jointly studied a tachylytic marginal facies of the dike occurring near the junction of the Lune with the Tees (**15**). In his 'Ancient volcanoes of Great Britain' Geikie drew attention to the probable continuation of the dike across south-west Scotland from the Solway to the Firth of Clyde (**9**, p. 144), but his statement that the suggested prolongation 'strikes out to sea near Prestwick' is too approximate to be a safe guide to its course. The dike in question leaves the Ayrshire coast at Barassie, north of Troon, and reappears at the other side of Irvina Bay, north of Saltcoats (see the one-inch geological map, Sheet 22, Scotland). It has also been stated that at the other end of its course the Cleveland dike is visible in Robin Hood's Bay, probably because it is shown as extending to the coast on the map of the volcanic districts of the British Isles by Geikie (**9**, end of vol. 2). Actually, however, the nearest exposure is nearly four miles from the Yorkshire coast.

Roughly midway between the boundary dikes a linear system of interrupted dikes can be traced from the Hebburn dike in the north-east corner of Durham, across the Tyne at Walker, through the Coley Hill dike near Newcastle-upon-Tyne, and the Bingfield dike east of the North Tyne to the Warksburn dike west of the North Tyne. In 1878 Lebour described the Coley Hill dike as a continuation of the Hebburn dike (**1**, p. 49), whereas Teall attempted to establish a connexion between the Coley Hill and Tynemouth dikes, basing this correlation on the similarity of their petrographic characters (**2**, p. 234). The field evidence is nevertheless in favour of Lebour's interpretation, though it should be clearly understood, as pointed out long ago by Winch, that the various sections of this dike system are not continuous either at the surface or in colliery workings. On the contrary, they consti-

tute a nearly linear echelon. In addition to describing the Hebburn dike, Teall gave an account of the Bingfield dike under the mistaken impression that he was dealing with Lebour's 'Brunton dike'. As pointed out in our former paper (**26**, p. 521), the latter, now known as the St. Oswald's Chapel dike, is a characteristic member of the Whin Sill suite of quartz-dolerite dikes. The rock of the Bingfield dike, on the other hand, has been adopted by the petrologists of the Geological Survey as the type example of the Brunton type of tholeiite (**22**, pp. 285 and 372). The Hebburn–Bingfield series continues across Scotland as the Eskdalemuir, Moffat, and Dalraith dikes. The last of these comes within half-a-mile of the Barrmill dike, to which it is parallel.

North of the Tyne a number of tholeiite dikes are exposed along the Northumberland coast. The Tynemouth dike was closely investigated by Teall with special reference to the occurrence within it of porphyritic aggregates of anorthite (**2**, p. 233) and spherical amygdales occupied by calcite or mesostasis or both (**7**). At the north end of the sands of Whitley Bay a dike having similar characters was discovered in 1912 by Dr. J. A. Smythe (**17**). Still farther up the coast is the Collywell dike described by Teall under the name 'Hartley dike'. Smythe has since applied the latter name to a dike which he found in the cliffs (also in 1912) 30 yards south of the Collywell dike. There are several parallel dikes in this neighbourhood forming a belt which is represented in the Wansbeck valley, 24 miles to the west, by the Crookdene and Ray Mill dikes. The former of these has been described in great detail by Miss Heslop and Dr. Smythe (**12**), who regarded it as a continuation of the Collywell dike. Figs. 1 and 3 suggest a correlation with the Whitley Bay dike. The Ray Mill dike and its numerous linear associates carry on the belt to Kielder on the North Tyne (**8**). In fig. 3 (p. 42) the belt referred to is shown within dotted lines.

The dikes that strike inland north and south of Blyth on the Northumberland coast have not been previously described, but the olivine-bearing tholeiite that crosses the Wansbeck near Morpeth is well known from Teall's account (**2**, p. 239). It has also been investigated, together with the Collywell and Tynemouth dikes, by Miss Heslop and Dr. Smythe (**12**). The Morpeth–Blyth zone of dikes is unrepresented by exposures farther inland until the headwaters of the North Tyne are reached in the neighbourhood of Deadwater and Kielderhead. The dikes of the Kielder district have been described

in detail by the late C. T. Clough (**8**). Farther on in Lanarkshire and Ayrshire the southern part of this composite zone is continued by the long dike which extends past Hart Fell, Muirkirk, and Barrmill, and by several shorter dikes that run parallel on the north-east. It is noteworthy that from sea to sea most of the northernmost members of the zone are found to be markedly olivine-bearing. North of the line of olivine-tholeiites lies the Acklington–Hawick dike and its long extension past Moneyacres towards Wemyss Bay and Cowal.

Five more or less definite lines or belts of dikes can therefore be recognized in the province (see fig. 3, p.42). In order from north to south these may be traced as follows:

(*a*) Acklington–Hawick–Moneyacres–Wemyss Bay–Cowal.

(*b*) Morpeth–Kielderhead–Middleton (Lugton)–Ayrshire coast (olivine-bearing dikes).

(*c*) Collywell-Blyth–Ray Mill – Deadwater – Hart Fell – Muirkirk – Barrmill.

(*d*) Hebburn-Bingfield–Eskdalemuir–Moffat–Dalraith.

(*e*) Cleveland–Armathwaite-Barassie–Stevenston–Great Cumbrae - Toward Point (Cowal).

The Scottish representatives of some of these dikes, particularly those in the Clyde area, have been described by Tyrrell (**19**), who was the first to point out that they provide a link between those of Mull and the north of England.

Direct field evidence of the age of the dikes is unfortunately scanty. The Cleveland dike is definitely post-Liassic, and this points at once to a Tertiary age. The Tynemouth dike was formerly to be seen cutting through the Permian Yellow Sands, according to Lebour (**3**, p. 87), but the critical section is no longer visible. A pre-Permian age has been thought possible in the case of the Hebburn dike because of the fact that it has not been found penetrating the Magnesian Limestone. Conversely, the presence of dolerite boulders on the beach at Whitburn has been held to suggest a post-Permian age. However, examination of thin sections of the boulders shows that most of them are of the Whin Sill type and that tholeiites are absent. Neither argument has therefore any application to the problem. From a petrological and tectonic point of view there can be little doubt that the dikes are of Tertiary age, forming as they do a single suite with obvious relations to the great igneous centre of Mull.

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26 1928 Holmes (A.) and Harwood (H. F.). The age and composition of the Whin Sill and the related dikes of the north of England. Min. Mag. London, vol. 21, pp. 493–452, and pl. X.

2. Types of Tholeiites.

Steininger's term *Tholeiite*[1] was adopted by Rosenbusch in his 'Mikroskopische Physiographie'[2] for certain intrusive rocks occurring in the Saar-Nahe district which are composed of a framework of calcic plagioclase, pyroxenes, and titanomagnetite with patchy interstices occupied by a mesostasis of glass, globulitic glass, or devitrification products. Some of the rocks contain idiomorphic olivine or enstatite, and in a few examples porphyritic augite occurs. Tholeiite, unqualified, was regarded as typically free or almost free from olivine; those with conspicuous olivine were distinguished as olivine-tholeiite. The essential features are thus the basaltic composition of the crystalline framework and the development of intersertal texture.

In describing the Tertiary igneous rocks of Mull the Survey petrologists found it convenient to restrict the application of the term tholeiite to non-porphyritic varieties (**22**, pp. 280 and 284), and these they found to have a silica percentage below 55. Tyrrell, on the other hand, in his descriptions of the dikes of Arran[3] and the Clyde area (**19**) employed the term to include not only the porphyritic types recognized by Rosenbusch, but also rocks carrying phenocrysts of plagioclase approaching anorthite in composition. In the Arran Memoir (p. 240) he has clearly summarized the distinguishing characteristics of the dolerite-tholeiite-tachylyte groups of rocks. With increasing silica percentage the tholeiites pass into rocks in which a more continuous groundmass takes the place of patchy intersertal

[1] J. Steininger, Geognostische Beschreibung des Landes zwischen der untern Saar und dem Rheine (Trier, 1840). Nachträge (Trier, 1841), p. 26. The rock to which the name was given occurs on the Schaumberg at Tholey in the Saar district. A chemical analysis of this rock was given by C. Bergemann in Karsten's Arkiv Min., 1847, vol. 21, p. 12.

[2] H. Rosenbusch, 2nd edition, 1887, vol. 2, p. 504.

[3] Mem. Geol. Survey, Scotland. The geology of Arran, 1928, p. 240.

mesostasis. From the point of view of petrogenesis these rocks may be quite distinct from pyroxene-andesites, and in classifying the Mull representatives the Survey have wisely kept the issue clear by giving them special names such as *leidleite* and *inninmorite* (**18** and **22**).

In the north of England few departures from the usual tholeiitic range of textures and compositions have been encountered. We shall use the terms *tholeiite* and *olivine-tholeiite* in the wider senses adopted by Tyrrell, limiting their application to particular rocks by reference to a series of closely defined types of which a number have already been discriminated by Tyrrell and the Survey petrologists.

Types of Olivine-tholeiites.

The Salen type.—Rocks of this type are defined in the Mull Memoir (p. 370) as 'even grained finely crystalline dark-grey rocks, usually without any trace of porphyritic constituents. Microscopically, they are seen to be composed mainly of augite and labradorite felspar, with subordinate olivine, iron-ore, and a variable quantity of residual glassy matter of relatively late consolidation. The augite is, usually, at least as prevalent as the felspar.' Ophitic texture is common. Among basalts the Salen type is represented by the Staffa type (**22**, p. 146), which includes the well-known columnar basalt of the Giant's Causeway. In some examples of the Salen type there is a suggestion of the stellate grouping of felspar laths which is a notable feature of the Brunton type. When this becomes characteristically developed with a marked increase in the proportion of mesostasis the rock is more conveniently described as belonging to an *olivine-bearing Brunton type.*

Tyrrell's *Corrie type* differs from the Salen type only in the possession of numerous small phenocrysts of bytownite-anorthite (**19**, p. 352). It corresponds chemically with the Porphyritic Central Magma-type of Mull. The *Largs type* of Tyrrell is further characterized by a greater abundance of olivine, which here occurs as large phenocrysts as well as in the groundmass. Whereas in the Salen and Corrie types the mesostasis is usually about 10 per cent., in the Largs type it is greatly reduced.

Types of Tholeiite without Essential Olivine.

The Brunton type.—In rocks of this type the mesostasis amounts to about 30 per cent., and intersertal texture is very conspicuously developed. Elongated laths of plagioclase embedded in, and radiating

out from, discrete clots of granular pyroxene form stellate clusters. The latter are commonly separated from one another by a dark brown mesostasis of glass with globulitic and acicular inclusions, but they may also interpenetrate or touch tangentially. The three chief constituents are commonly present in about equal proportions. The black ores are rarely well crystallized and are for the most part restricted to the mesostasis. See pl. I, figs. 2–6, which illustrate the highly characteristic appearance of the Brunton type. The classic example is the rock of the Bingfield dike, Northumberland, first described by Teall (**2**, p. 236), and adopted in the Mull Memoir as the standard of the type (**22**, p. 372). As stated above, olivine may be present as a minor but essential constituent in certain rocks which otherwise have the distinguishing features of the Brunton type.

The Talaidh type (pronounced Tala) is described in the Mull Memoir (p. 284) as approaching leidleite 'in the frequent tendency to elongation of the augite'. Sheaves and fan-shaped cervicorn groups of slender augites fringed with grains of the black ores are present, as well as ophitic plates and columnar crystals. Acicular crystallization is common in the devitrified mesostasis.

The Acklington type, not previously described under this specific name, differs from the Brunton and Talaidh types in the absence of radiating sheaves of augite and the rarity of stellate clustering among the felspars. Haphazard strings and groups of granular or columnar augite are common; the felspars are in broader prisms and the black ores are generally sharply crystallized and evenly distributed. The mesostasis is abundant and may be a clear colourless to sepia glass or more generally a turbid product of devitrification; in both types globulites and skeletal reticulations of ores are abundant.

Some Northumbrian examples of the above three types carry corroded or fretted phenocrysts and aggregates of anorthite or bytownite-anorthite sharply zoned with a rim of less calcic plagioclase. For convenience these felspars will be referred to as anorthite, as internally they never fall appreciably below An_{90}. It does not seem expedient to continue to erect new types to distinguish the anorthite-bearing varieties from the normal types. The rock of the Tynemouth dike is sufficiently described as an anorthite-bearing Brunton type; that of Crookdene as an anorthite-bearing Talaidh type; and that of Coley Hill as an anorthite-bearing Acklington type.

The Cleveland type differs from the Acklington type mainly in the possession of numerous and evenly distributed small phenocrysts of

TABULAR CLASSIFICATION OF THOLEIITES AND RELATED TYPES.

[The names of types that are porphyritic (apart from the presence of anorthite) are printed in CAPITALS.]

	Pyroxenes not conspicuously elongated; equidimensional plates and granular aggregates common.		Range of SiO_2 %.	Pyroxenes columnar to slender: sheaf-like groupings characteristic.	
	Anorthite absent or inconspicuous.	Anorthite-bearing.		Anorthite-bearing.	Anorthite absent or inconspicuous.
With essential olivine.	LARGS TYPE, Ayrshire (Porphyritic olivine).		42 to 46		
	Salen type, Mull ... Olivine-bearing Brunton type.	Corrie type, Arran	47 to 50		
Without essential olivine.	Brunton type, Bingfield, Northumberland.	Anorthite-bearing Brunton type, e.g. Tynemouth, Northumberland.	50 51 52	Anorthite-bearing Talaidh type, e.g. Crookdene, Northumberland.	
	Acklington type, Northumberland.	Anorthite-bearing Acklington type, e.g. Coley Hill, Northumberland.	53 54 55 56 57 58		Talaidh type, Mull.
	CLEVELAND TYPE, north of England (Porphyritic plagioclase and pyroxene).	CUMBRAE Great (Pyroxenes, granular,	59 60 61 62 63 64	TYPE, Cumbrae columnar, and slender). INNINMORITE, Mull.	Leidleite, Mull.

plagioclase and pyroxenes, in which respect it approaches inninmorite. The rock of the Cleveland dike is so well known and so remarkably uniform over long stretches of its course that it would be inappropriate to describe it merely as a porphyritic example of the Acklington type. Not only does the Cleveland type represent a link between the Acklington type and inninmorite, but it also has many features in common with Tyrrell's *Cumbrae type* (**19**, p. 306). The latter differs mainly in the possession of conspicuous aggregates and phenocrysts of anorthite. In the Arran Memoir (p. 253) Tyrrell states that the groundmass is of Brunton type, especially rich in glass or its devitrified equivalent, but since in many specimens the groundmass shows little trace of stellate clustering,[1] it could now be more accurately described in terms of the new Acklington type. In the nomenclature here developed these varieties of the Cumbrae type represent a Cleveland type in which all the phenocrysts of plagioclase approximate to anorthite. There are other varieties, however, that resemble anorthite-bearing leidleite.

The Dalmahoy type of tholeiite[2] has a texture not unlike the Acklington type, but is distinguished by a high proportion of plagioclase relative to pyroxene, abundance of chlorophaeite, and a chemical likeness to the mugearites. No tholeiites having this assemblage of characters have been found in the north of England, and so far those recognized in Scotland are of Carboniferous age.

3. The Salen Type and other Olivine-Tholeiites.

The course of the Kielderhead dike has been described by Clough (**8**, p. 18), who states that hand-specimens 'show prominent porphyritic crystals of felspar'. Such specimens would correspond to the Corrie type, but, as those which we have collected are almost devoid of phenocrysts, they must be referred to the Salen type (pl. I, fig. 1).

Olivine crystals are conspicuous; as noted by Teall (**8**, p. 19) they are much broken and fissured, and serpentinization is general around borders and along cracks and has in places become complete. Felspar

[1] Tyrrell, for example, has indicated this departure from the normal appearance by the expression 'cf. Brunton'. The analysis of a 'cf. Brunton' rock (Arran Memoir, p. 254, no. 21) shows 54·52 per cent. of silica, corresponding with the Acklington type.

[2] R. Campbell and J. W. Lunn, The tholeiites and dolerites of the Dalmahoy syncline. Trans. Roy. Soc. Edinburgh, 1927, vol. 55, pt. ii, no. 21, pp. 489–505.

laths appear to be included within the larger olivines, but careful examination shows that this is due to later penetration between the disrupted and altered cores. No aggregates of olivine and felspar such as occur in the Largs type have been detected. Small inclusions of olivine rimmed with serpentine are to be found in some of the larger plates of augite. No certain trace of rhombic pyroxene has been found. The augite is colourless to pale yellowish-brown, the tint darkening outwards, and here and there becoming faintly purple-brown and pleochroic, especially in contact with titanomagnetite. Its relations with plagioclase are characteristically ophitic. A few small aggregates of externally zoned bytownite are present (about An_{75} with borders ranging from An_{50} to An_{30}). The common felspar laths are zoned throughout, the change accelerating towards the boundaries, which are about An_{30}, from an internal composition near An_{55}. Many of the laths are in pairs crossing at acute angles, but stellate clustering is not otherwise suggested. The ores are in sharply crystallized individuals or skeletal rows scattered between the other minerals of the rock with a special tendency to cling to the plates and grains of augite. The mesostasis is a nearly colourless to turbid brown glass charged with black globulites and skeletal growths and colourless acicular ill-defined microlites. Its distribution is patchy, some parts of a section showing very little, while others contain it conspicuously. Green-stained chalcedony also occurs irregularly as interstitial material, but this constituent is more abundant in small spherical amygdales sometimes enclosing a core of calcite.

The Kielderhead dike is continued across the Border in the well-exposed Peel Burn dike three-quarters of a mile north of the summit of Peel Fell, and in the Fanna dike, exposed in the Singdean Burn just over three miles farther on to the WNW. The Peel Burn dike (478) is of the Brunton type, but carries a little serpentinized olivine with few fresh cores (pl. I, fig. 2). The Fanna dike (464) is again olivine-bearing and has a remarkable resemblance to the Morpeth dike. It represents a passage between the Salen and olivine-Brunton types. The mineral compositions are listed below.

South of the Kielderhead line two parallel dikes cross the Deadwater Burn near Deadwater Farm (**8**, p. 19). Of these the rock of the northern dike is a Talaidh type, but that of the southern (437) is almost identical with the Kielderhead rock described above. It is less rich in olivine and in places has, exceptionally, very little mesostasis. No exposure is now visible in the Burn, but boulders of the

rock are common (together with others of the northern dike and erratics of Lower Carboniferous basalts), and the dike itself is found in situ near the head of the small sike immediately to the east, some 300 yards from the farmhouse. The specimens collected in situ contain tiny amygdales of chalcedony. Clough mentions 'spherical pinhead vesicles filled with calcite' (**8**, p. 19), and boulders answering this description have been found in the Burn.

The Morpeth dike is also of the Salen type, but, as the published descriptions indicate (**2**, p. 239; and **12**, p. 14), there is a close resemblance to the rock of the Tynemouth dike, apart from the rarity of anorthite aggregates and the presence of olivine. The Morpeth dike thus represents an approach to the Brunton type, of which the Tynemouth dike is an anorthite-bearing example. The chief differences from the Kielderhead rock are increased proportions of mesostasis and amygdales, a slight decrease in olivine, and a noticeable tendency to diverse groupings among the felspar laths. Some of the augites have crystallized in roughly spherical groups of half a dozen radial sectors, of which opposite members extinguish simultaneously. The neighbouring dike of Bothal Woods also exhibits characters which are intermediate between those of the Salen and Brunton types. The West Sleekburn dike and its continuation beyond the coast (the Narrow Bords dike, exposed in the Low Main level of the Mill Pit, near Blyth) is an excellent representative of the olivine-bearing Brunton type.

Mineral composition.—The following table sets forth the results of a series of measurements made with a Shand micrometer. The figures in this and succeeding tables of the same kind are percentages by volume, except in the last column, where the ratio of felspar to the sum of pyroxenes (including olivine where present) and felspar is stated as a percentage.

Mineral proportions of Olivine-tholeiites.

Dikes.	Mesostasis.	Olivine[1] (O).	Pyroxenes (P).	Felspar (F).	F/(O+P+F).
307. Kielderhead ...	10·1	12·7	37·2	34·3	41 %
306. Kielderhead ...	12·3	10·2	34·7	33·0	42
478. Peel Burn ...	23·8	4·1	31·8	28·2	44
464. Fanna	17·6	7·4	36·1	30·1	41
341. Morpeth... ...	16·3	8·7	35·5	29·8	40
484. Narrow Bords	19·8	7·8	34·2	31·6	43

[1] Includes serpentine.

The results indicate a rather striking inverse relationship between olivine and mesostasis.[1] This may be regarded as continuing in the Brunton type where, with little or no olivine, the mesostasis rises to 30 per cent. or more. The possible implications of this interesting observation will be referred to in discussing the Brunton type (p. 24).

Chemical composition.—A fresh and typical specimen of the Kielderhead dike was sampled for analysis. The specimen (306) was from an exposure in a little sike that enters the Scalp Burn from the east about a mile up-stream from the junction of the Scalp Burn and the White Kielder. The results are tabulated below together with the norm and the 'calculated mineral composition', arrived at by the

Chemical composition of the Kielderhead Dike (306).

	Per-centages.	Molecular proportions.
SiO_2	50·41	0·8391
Al_2O_3 ...	15·14	0·1485
Fe_2O_3 ...	2·71	0·0169
FeO	7·95	0·1104
MgO	6·57	0·1643
CaO	11·30	0·2018
Na_2O	2·29	0·0369
K_2O	0·82	0·0087
H_2O (+110° C.)	1·01	0·0561
H_2O (−110° C.)	0·72	0·0400
CO_2	0·07	0·0016
TiO_2	1·30	0·0163
ZrO_2	none	—
P_2O_5	0·15	0·0011
Cl	trace	—
S	0·06	0·0019
Cr_2O_3 ...	trace	—
V_2O_3	0·05	0·0003
NiO	none	—
MnO	0·17	0·0024
SrO	0·05	0·0005
BaO	0·03	0·0002
Li_2O	trace	—
	100·80	
Less O for S	0·02	
	100·78	

Specific gravity = 2·98

Norm.			
Quartz			1·43
Orthoclase			4·84
Albite			19·35
Anorthite			28·70
Diopside	$CaSiO_3$	10·89	21·27
	$MgSiO_3$	6·34	
	$FeSiO_3$	4·04	
Hypersthene	$MgSiO_3$	10·01	16·37
	$FeSiO_3$	6·36	
Magnetite			3·94
Ilmenite			2·46
Pyrite			0·12
Apatite			0·37
Calcite			0·16
			99·01
Water			1·73
			100·74

Calculated mineral composition.	
Quartz	2·53
Alkali-felspars, $Or_{40}Ab_{60}$ ...	0·10
Plagioclase, $An_{49}Ab_{41}Or_{10}$ ...	47·67
Pyroxenes	41·65
Ores (as above)	6·52
Apatite	0·37
Calcite	0·16
	99·00

[1] The Deadwater south dike appears to be an exception to this rule.

Analyses of Olivine-tholeiites.

Salen and Corrie types.

	1. Kielderhead.	A. Ayrshire.	B. Bute.	C. Mull.	D. Arran.
SiO_2 ...	50·41	48·63	48·92	47·35	48·60
Al_2O_3 ...	15·14	13·23	14·25	13·90	18·27
Fe_2O_3 ...	2·71	3·16	1·95	5·87	3·19
FeO ...	7·95	7·62	11·54	8·96	7·17
MgO ...	6·57	7·97	5·56	5·97	6·29
CaO ...	11·30	12·30	10·23	10·65	10·15
Na_2O ...	2·29	1·20	2·67	2·73	1·63
K_2O ...	0·82	1·13	1·01	0·54	0·45
H_2O+ ...	1·01	0·65	0·45	1·16	1·65
H_2O- ...	0·72	0·75	0·82	1·04	1·60
CO_2 ...	0·07	0·21	trace	0·32	none
TiO_2 ...	1·30	2·32	1·88	1·75	0·70
P_2O_5 ...	0·15	0·01	0·17	0·24	0·09
S	0·06	—	—	0·23	trace
FeS_2 ...	—	0·37	0·30	—	—
Cr_2O_3 ...	trace	0·04	—	—	—
V_2O_3 ...	0·05	—	—	—	—
MnO ...	0·17	0·21	0·27	0·23	0·24
BaO ...	0·03	0·00	—	—	—
	100·80	99·80	100·20	100·94	100·03

1. Olivine-tholeiite (Salen type), Kielderhead, Northumberland. Analyst, H. F. Harwood (supra, p. 15). Total includes SrO 0·05.

A. Tholeiitic olivine-dolerite, NW. dike, 400 yards west of Middleton, near Lugton, Ayrshire. Analyst, B. E. Dixon (**23**, p. 128, no. 802).

B. Olivine-tholeiite (Salen type), 12-foot dike on foreshore of Kilchattan Bay, Bute. Analyst, W. H. Herdsman. Unpublished analysis by courtesy of Mr. H. J. W. Brown. See Geol. Mag., 1929, vol. 66, p. 94.

C. Olivine-tholeiite (Salen type), dike on the shore $2\frac{1}{2}$ miles NNW. of Salen, Mull. Analyst, F. R. Ennos, Mull Memoir, 1924, p. 17, no. I.

D. Olivine-tholeiite (Corrie type), dike on the shore $1\frac{3}{4}$ miles south of Corrie Hotel, Arran. Analyst, W. H. Herdsman, Arran Memoir, 1928, p. 254, no. 20.

empirical method outlined in our former paper (**26**, p. 512).[1] There is no very marked difference in composition between this example of the Salen type and the Whin Sill type of quartz-dolerite (see p. 23), but magnesia is higher, as might be expected, and lime and alumina are higher in accordance with the greater abundance of anorthite in the felspar; balancing these differences the oxides of iron and titanium

[1] For data of the distribution of orthoclase in plagioclase see J. H. L. Vogt, The physical chemistry of the magmatic differentiation of igneous rocks. II. On the felspar diagram. Oslo, 1926, p. 48.

are lower. The small amount of normative quartz is accounted for by the amygdales present, but as this silica is clearly of late magmatic origin (since the minerals crystallizing after the early serpentinization of the olivine have remained perfectly fresh), the original magma must itself be regarded as having been slightly oversaturated in silica.

The analysis is repeated on p. 16 for comparison with that of other olivine-tholeiites from Ayrshire, Bute, Mull, and Arran. Each of these, like the Kielderhead tholeiite, is shown by the possession of normative quartz to represent a mildly oversaturated magma. It is noteworthy that the dike near Lugton, analysis A, is in the same line of dikes as that to which the Morpeth and Kielderhead series belong.

4. The Brunton Type.

The Bingfield dike.—The type-example of the Brunton type of tholeiite is the rock of the Bingfield dike which is exposed on the south bank of the Redhouse Burn close to the fifth milestone from Corbridge on the Watling Street. The hamlet of Bingfield lies half a mile to the north-east.

The circumstances which led to the adoption of the name *Brunton* have been described in a former paper (**26**, p. 520) and no further reference is necessary here, except a reminder that Teall described the rock under the name ' Brunton Dyke ' (**2**, p. 236). Under the microscope the rock has an unmistakably characteristic appearance. It has been figured by Teall, Harker, and ourselves (**26**, pl. X, fig. 4). Other rocks of identical texture are also figured in plate I. Less typical are the figures by Tyrrell (**19**, p. 351) and the Geological Survey (Mull Memoir, fig. 62, p. 371).

As noted by Teall, glomeroporphyritic aggregates of plagioclase are not entirely absent, but they are small and easily overlooked. Measurements of extinction-angles and refractive indices on cleavage flakes of known orientation show that the composition lies near An_{88}, the extreme estimates being An_{84} and An_{92} in different specimens. External zoning is present exactly as in the larger aggregates of the Tynemouth dike. The long diversely arranged felspar laths of the body of the rock are mainly about An_{60}. Zoning is not conspicuous and does not appear to range beyond An_{40} on the borders of the broader crystals. The pyroxene plates and interdigitated granules are nearly colourless to pale grey-green and show very little of the patchiness of the Kielderhead pyroxene. A little enstatite or hypersthene is prob-

Chemical composition of the Bingfield Dike (370), Brunton type.

	Percentages.	Molecular proportions.
SiO_2	50·07	0·8337
Al_2O_3	14·53	0·1425
Fe_2O_3	1·76	0·0110
FeO	8·26	0·1150
MgO	6·77	0·1680
CaO	11·50	0·2051
Na_2O	1·93	0·0311
K_2O	0·85	0·0090
H_2O (+110° C.)	0·82	0·0456
H_2O (−110° C.)	0·52	0·0289
CO_2	1·61	0·0366
TiO_2	1·14	0·0142
ZrO_2	none	—
P_2O_5	0·16	0·0011
Cl	trace	—
S	0·08	0·0025
Cr_2O_3	0·02	0·0001
V_2O_3	0·06	0·0004
NiO	none	—
MnO	0·19	0·0027
SrO	0·02	0·0002
BaO	0·04	0·0003
Li_2O	trace	—
	100·33	
Less O for S ...	0·03	
	100·30	

Specific gravity = 2·91

Norm.		
Quartz		3·95
Orthoclase		5·01
Albite		16·30
Anorthite		28·59
Diopside	$CaSiO_3$ 7·26 $MgSiO_3$ 4·06 $FeSiO_3$ 2·90	14·22
Hypersthene	$MgSiO_3$ 12·80 $FeSiO_3$ 9·13	21·93
Magnetite		2·55
Ilmenite		2·16
Pyrite		0·14
Apatite		0·37
Calcite		3·66
Chromite		0·02
		98·90
Water		1·34
		100·24

Calculated mineral composition.	
Quartz	5·03
Alkali-felspar, $Ab_{60}Or_{40}$ ...	1·30
Plagioclase, $An_{54}Ab_{36}Or_{10}$ ...	43·62
Pyroxenes	40·05
Ores	4·87
Apatite	0·37
Calcite	3·66
	98·90

ably present but has not been determined with certainty. The norm shows that the common pyroxene must belong to the hypersthene-augites, and this is confirmed by the optical properties. The restriction of the ores (including pyrite) to the mesostasis is a constant feature. The residual material is dark brown and opaque, and highly charged with black skeletal ores and tapering rods. It makes up about a third of the whole rock and forms a background against which the clustering segregations of plagioclase and pyroxene stand out in strong relief. Here and there the mesostasis clears to irregular patches of calcite, including or bordered with pyrite; calcite is also present in small spherical amygdales. Near the contact (366) the dike is poorly crystallized (small laths of felspar alone being determinable), and highly charged with calcite amygdales and veins. There are

occasional thin linings of chalcedony, and irregular streaks and patches of pyrite are common in and around the amygdales and in the dark brown groundmass. The mineral proportions are given in the table on page 20.

Chemical composition.—As the type example of the Brunton tholeiite has hitherto remained unanalysed, a fresh specimen of the Bingfield dike reasonably free from amygdales was selected for analysis. The composition turns out, rather surprisingly, to be practically identical with that of the Kielderhead dike, except that the carbon dioxide is higher. Comparison of the ' calculated mineral composition ' of the rock as a whole with the mode and with the Kielderhead rock shows that the mesostasis must contain the ingredients of plagioclase with almost as much anorthite as the crystallized felspar, together with the equivalent of part of the pyroxene and most of the ores. Trial calculations show that the composition of the mesostasis is as basic as the rock as a whole, and that it does not correspond to any known Tertiary type of tholeiite (p. 47). It does, however, show a definite approach towards a trachybasaltic type of magma.

The Warksburn dike (363) is exposed three miles due west of Wark village in the banks of the stream after which it is named, the best exposure being on the north bank below Horneystead Farm. It is almost exactly in line with the Bingfield dike, although the two are ten miles apart. The rock differs very slightly from that of Bingfield in having pyroxene in higher proportion; mesostasis relatively diminished; and ores, though still restricted to the interstitial matter, more distinctly individualized (pl. I, fig. 6). The anorthite aggregates are small and sparsely distributed, and correspond to An_{96}.

The Ray Mill dikes.—Eight miles north of the Bingfield-Warksburn line there are exposures of a number of short dikes which form an echelon series. Those that have been visited and examined are from west to east: (*a*) *Lisles Burn* (Acklington type); (*b*) *Cross Hollows* (Acklington type), exposed on the south bank of the Ray Burn west of Ray Mill; (*c*) *Ray Mill* (Brunton type), exposed in the little dene between Ray Mill and the road to Cornhills; (*d*) *Horncastle Wood* (Brunton type), lying well within the wood on the east side of the road; and (*e*) *Castle Dene* (Talaidh type), at the eastern end of Horncastle Wood. *The Crookdene dike* (Talaidh type) lies $1\frac{1}{4}$ miles south of Cross Hollows. Of these the Horncastle Wood dike differs from the Bingfield rock only in the better crystallization of its

ores and in the possession of small circular amygdales occupied by chlorophaeite or interstitial matter, or occasionally by both, calcite being rare. In the Ray Mill dike the Brunton texture is developed even more strikingly than in the type-rock. The ores are here confined to minute rods thickly sprinkled through the mesostasis which in consequence is nearly black (pl. I, fig. 5). The amygdales, which are numerous on the sides of the dike, are varied and interesting. Some contain opal surrounding chalcedony; others have calcite in the interior; others contain calcite and chlorophaeite; and in some chlorophaeite occurs alone. As in Horncastle Wood, so here interstitial matter is a common infilling, sometimes alone, sometimes partly enclosing semilunar or spherical spaces occupied by chlorophaeite and calcite. The order of deposition appears to be mesostasis, opal, chalcedony, chlorophaeite, and calcite, with some overlapping of the last three.

Mineral proportions of Tholeiites of the Brunton type.

Dikes.	Mesostasis.	Pyroxenes (P).	Felspars (F).	F/(P+F).
369. Bingfield [1] ...	34·7	32·3	29·6	48 %
363. Warksburn ...	36·1	36·2	24·8	41
364. Warksburn ...	n.d.	30·1	27·4	48
330. Horncastle Wood	32·6	35·3	28·2	44
340. Ray Mill ...	37·2	29·7	26·7	47
358. Tynemouth [2] ...	28·8	34·3	32·2	48
482. Barrington ...	29·4	31·3	33·6	52

[1] For five sets of measurements see our Whin Sill paper (**26**, p. 521).

[2] These figures refer only to the groundmass, which makes up 92 % of the rock, the remaining 8 % being represented by megascopic anorthite.

The Tynemouth dike.—As a result of its investigation by Teall, this dike has become particularly well known (**2**, p. 233), and a later paper of two pages in which the cooling history is discussed has become one of the classics of petrological literature (**7**). The rock is noteworthy in containing large aggregates of anorthite, the individuals in contact with the groundmass showing definite faces within a sharply-zoned peripheral rim which is commonly toothed and serrated (pl. I, fig. 4). Streaks of inclusions of mesostasis are sometimes present just inside and roughly parallel to the zoned rim. Inside the periphery of each group the contacts of the anorthite individuals among themselves lack these features; as noted by Teall 'the internal relations . . . are those of plutonic rocks'. The composition as given by Stead's analysis corresponds to An_{85} (**2**, p. 234), but refractive index determinations, confirming Teall's deduction from

Chemical composition of the Tynemouth Dike (358).

	Per-centages.	Molecular proportions.
SiO_2	50·81	0·8459
Al_2O_3... ...	15·70	0·1536
Fe_2O_3... ...	2·80	0·0175
FeO	6·02	0·0838
MgO	6·41	0·1590
CaO	12·17	0·2171
Na_2O	1·96	0·0316
K_2O	0·87	0·0092
H_2O (+110° C.)	1·01	0·0561
H_2O (−110° C.)	1·21	0·0672
CO_2	0·55	0·0125
TiO_2	0·81	0·0101
ZrO_2	none	—
P_2O_5	0·10	0·0007
Cl	trace	—
S	0·12	0·0037
Cr_2O_3... ...	trace	—
V_2O_3	0·04	0·0003
MnO	0·17	0·0024
SrO	none	—
BaO	0·02	0·0001
Li_2O	trace	—
	100·77	
Less O for S ...	0·04	
	100·73	

Norm.		
Quartz		4·17
Orthoclase		5·12
Albite		16·58
Anorthite		31·57
Diopside	$CaSiO_3$ 10·32 $MgSiO_3$ 6·57 $FeSiO_3$ 3·09	19·98
Hypersthene	$MgSiO_3$ 9·38 $FeSiO_3$ 4·40	13·78
Magnetite		4·05
Ilmenite		1·53
Pyrite		0·22
Apatite		0·23
Calcite		1·25
		98·48
Water		2·22
		100·70

Calculated mineral composition.	
Quartz	5·19
Alkali-felspar, $Ab_{60}Or_{40}$ ...	0·78
Plagioclase,[1] $An_{56}Ab_{34}Or_{10}$ ...	47·76
Pyroxenes	37·42
Ores	5·80
Apatite	0·23
Calcite	1·25
	98·43

Specific gravity = 2·84

[1] Includes about 8 % of An_{85}, the remaining 40 % being approximately An_{50}.

extinction-angles, show that, excluding the zoned rim, the felspar is not below An_{90}. The distribution of the aggregates is not uniform, some specimens being nearly free from megascopic anorthite, while in others the proportion may rise to fully 10 per cent. Parts of the rock that are rich in amygdales rarely contain visible felspars. The general mass of the rock is identical with the Brunton type of Bingfield and calls for no further description. The mineral composition is given above (p. 20).

The Whitley Bay dike is also of the Brunton type. Smythe states that the felspars ' are frequently arranged in star-like clusters ' and notes the resemblance of the rock to that of the Tynemouth dike (**17**, p. 331). *The Barrington dike* (482) west of Blyth is of Brunton type in part, but some specimens show a passage to the Acklington type.

Chemical composition.—A specimen of the Tynemouth dike was analysed, because it was thought unlikely that Stead's old analysis could be fairly representative of the rock. A specimen collected by Teall from Tynemouth station was selected (358). It contained about 8% of megascopic anorthite and only a few pin-head amygdales. The results gave 50·81 % of SiO_2 and 6·41 % of MgO in place of 58·30 and 2·68, the respective figures recorded by Stead. The analysis as a whole differs from that of the Bingfield rock only in showing slightly higher CaO and Al_2O_3, as would be expected.

In the adjoining table the analyses of the Bingfield and Tynemouth rocks are repeated for comparison with those of the Mull examples of the Brunton type, and an average of six analyses of the Whin Sill type of quartz-dolerite is added. It will be observed that the last does not differ in any significant way from the average Brunton composition. The Bingfield rock has lower iron-oxides and soda, but the Mull examples are higher in these constituents. The Bingfield magnesia is higher, but in the Mull rocks it is lower. The average Brunton type, with one-third of its substance remaining as a mesostasis of glass and poorly crystallized material, is apparently chemically identical with the Whin Sill type which is holocrystalline or nearly so.

Furthermore, on comparing the Salen types of the Firth of Clyde and Mull areas (p. 16) with the Brunton types of Mull, the differences in chemical composition are seen to be of the right order to accord with the presence of olivine in the former. Between the Kielderhead and Bingfield rocks, however, there are no obviously adequate differences. We have therefore to try and explain: (*a*) the presence of relatively abundant glass in the Brunton type, and (*b*) the appearance of olivine in the Kielderhead dike and its absence from, or paucity in, the Bingfield dike.

The mesostasis cannot be a result of sudden chilling following a final act of injection after the main crystallization had already been achieved. The texture is too delicate to bear such an interpretation, and, moreover, the grain becomes finer towards the edges and fades away into a vitreous border containing of the earlier minerals only minute felspar laths. The only other possibility appears to be akin to that suggested by Anderson and Radley in their investigation of the pitchstones of Mull (**18**), namely, that the primary content of water and other volatiles may steadily increase in the residual magma until it reaches such a proportion that crystallization can no longer continue. That this may indeed afford the basis of an explanation is supported

Analyses of the Whin Sill and of Tholeiites of the Brunton type.

	Whin Sill type.	2. Bingfield.	3. Tynemouth.	E. Mull.	F. Mull.
SiO_2 ...	50·52	50·07	50·81	51·53	51·63
Al_2O_3 ...	13·76	14·53	15·70	11·05	11·77
Fe_2O_3 ...	3·87	1·76	2·80	2·73	3·23
FeO ...	8·50	8·26	6·02	10·98	10·47
MgO ...	5·42	6·77	6·41	5·21	5·02
CaO ...	9·09	11·50	12·17	9·68	9·34
Na_2O ...	2·42	1·93	1·96	3·48	2·90
K_2O ...	0·96	0·85	0·87	0·86	0·91
H_2O+ ...	1·51	0·82	1·01	1·26	1·40
H_2O- ...	0·76	0·52	1·21	0·71	0·68
CO_2 ...	0·58	1·61	0·55	0·08	0·11
TiO_2 ...	2·39	1·14	0·81	1·57	2·00
P_2O_5 ...	0·26	0·16	0·10	0·22	0·29
S ...	0·06	0·08	0·12	—	—
FeS_2 ...	—	—	—	0·26	0·08
Cr_2O_3 ...	trace	0·02	trace	—	—
V_2O_3 ...	0·05	0·06	0·04	—	—
(Co,Ni)O	none	none	none	nt. fd.	0·04
MnO ...	0·16	0·19	0·17	0·45	0·35
SrO ...	trace	0·02	none	—	—
BaO ...	0·03	0·04	0·02	nt. fd.	0·03
	100·34	100·30	100·77	100·07	100·27

Whin Sill type. Average of six analyses of the Whin Sill and related quartz-dolerite dikes. Analyst, H. F. Harwood, Min. Mag., 1928, vol. 21, p. 530.

2. Tholeiite (Brunton type), Bingfield dike, Redhouse Burn, Northumberland (type locality). Analyst, H. F. Harwood (supra, p. 18).

3. Anorthite-bearing tholeiite (Brunton type), Tynemouth dike, Tynemouth Station, Northumberland. Analyst, H. F. Harwood (supra, p. 21).

E. Tholeiite (Brunton type), dike on shore 5½ miles SE. of Tobermory, Mull. Analyst, E. G. Radley (**22**, p. 17).

F. Tholeiite (Brunton type), dike on shore ¼ mile N. of Kintallen, Mull. Analyst, E. G. Radley (**22**, p. 17).

by the observation that there appears to be a rough relation between the proportions of calcite amygdales and mesostasis. Clough makes an indirect reference to this in the case of the Kielderhead dike (**8**, p. 18), and Teall notes that in the Morpeth dike the amygdales ' are not nearly so abundant or so large as in the Tynemouth rock ' (**2**, p. 239). Field comparisons of dikes of the Salen and Brunton types, though not amenable to quantitative expression, suggest that there is some connexion between the original content of volatile constituents in the magma, notably carbon dioxide, and the proportion of residual magma that failed to crystallize effectively. Carbon dioxide was

demonstrably far more abundant in the magma from which the Bingfield rock consolidated than in those of the Kielderhead dike and the Whin Sill, and this gas, possibly aided by water, was probably the inhibiting agent. It should be noted that chemical analyses are not as a rule made with a view to testing hypotheses such as this, for specimens with conspicuous amygdales are usually avoided as far as possible. In this respect the interpretation of analyses must be guided by field observations.

The olivine problem may also be solved by experimental work designed to test similar considerations. As we have seen, the proportion of olivine varies inversely with that of mesostasis, and therefore, presumably, inversely with that of calcite amygdales, and, finally, inversely with that of the volatile constituents in the magma. Is it possible that the latter inhibit the crystallization of olivine or bring about its early resolution? A partial association has been demonstrated, but in the absence of positive experiments the evidence as yet will hardly bear an assumption of causation.

5. The Talaidh Type.

The Coastal region.—Of the tholeiite dikes previously described by other authors, the ' Seaton and Hartley ' dikes of Teall (**2**, p. 237) and the Collywell and Crookdene dikes of Miss Heslop and Smythe (**12**) belong to the Talaidh type. They are distinguished by the development of elongated pyroxenes often in radiating sheaves and feathery growths. It should be noted that in all Talaidh types clots of minutely granular augite may be seen wherever a section has cut across a sheaf-like bundle. The grain is generally finer than that of the Salen and Brunton types, and as a rule the patches of dark brown mesostasis are smaller and more numerous, and, as a result of much incipient crystallization, less sharply differentiated from the well-crystallized phases. The total amount of mesostasis falls between the average Salen and Brunton proportions.

Chemically, as shown by the two analyses by Smythe quoted on p. 28 the rocks of the Collywell and Crookdene dikes show a general resemblance to those of the Brunton type. Although neither of these dikes is variegated with anorthite crystals and aggregates as conspicuously as the Tynemouth dike, small patches of a similar felspar can generally be found in them without difficulty, and in the Crookdene dike Smythe discovered an aggregate six inches long. Analyses

by Smythe of this material and of felspar aggregates separated from two other dikes are quoted below. The lower anorthite content of the latter relative to that of the much larger Crookdene aggregate is a necessary consequence of inclusion in the analysed material of a higher proportion of the zoned rims. Refractive index measurements and extinction-angles on basal plates suggest that internally all three felspars are about An_{94}–An_{96}.

In addition to the Seaton Sluice and Collywell dikes another of the dikes of the coastal region in the neighbourhood of Blyth is also of the Talaidh type. This is shown on the map, fig. 1, as the North Blyth dike. It is exposed in the Low Main level of the Isabella Pit, and, although somewhat altered, the rock (483) is clearly identical in texture with that of the Seaton Sluice dike.

Analyses of anorthite aggregates in Tholeiites of the Talaidh type, Northumberland (by J. A. Smythe).

	Crookdene (12, p. 7).	Hartley[1] (17, p. 336).	Collywell (12, p. 7).
SiO_2...	45·88	45·77	46·61
Al_2O_3	34·31	34·20	35·13
Fe_2O_3	0·83	0·73	0·25
CaO	18·28	18·52	16·74
Na_2O	0·82	1·04	1·05
K_2O...	0·11	0·12	0·15
H_2O...	0·14	0·25	0·22
TiO_2	0·04	trace	0·13
	100·41	100·63	100·28
Norm (recalculated to 100%).—			
Anorthite	92·18	90·23	89·49
Albite	7·12	9·03	9·55
Orthoclase	0·70	0·74	0·96
	100·00	100·00	100·00

[1] This is Smythe's Hartley dike, thirty yards south of the Collywell dike.

Mid-Northumberland.—It is noteworthy that all the Talaidh types lie in a single broad belt defined at the coast by the Collywell-Blyth group of dikes (fig. 3). In mid-Northumberland the belt is represented by the Crookdene and Castle Dene dikes and on the Border by the dikes near Kielder and the northern member of the two Deadwater dikes. Other types of tholeiites occur within this belt, but outside it Talaidh types have not yet been found.

Although the Ray Mill and Horncastle dikes are typical Brunton

types, their immediate neighbour to the east, the Castle Dene dike, is of very different texture. Certain parts resemble the Crookdene dike in every essential respect, while other sections show a passage towards the granular Acklington type, but in so far as sheaves of augite are nowhere absent, the dike may be described as Talaidh.

The Border.—The northern Deadwater dike has been traced in Kittythirst sike east of the farmhouse, and in the sikes between Deadwater and Saughtree stations to the north-west of the farm. From east to west the tendency to elongation and radial groupings of the augite becomes steadily more pronounced, culminating in the Windy Knowe exposure which provides an exceptionally good example of the Talaidh type. In the other direction (e. g. Kittythirst, 442) plates of nearly colourless pyroxene (some of which is probably orthorhombic) become more abundant, and the granular habit of the Brunton type begins to take the place of the Talaidh sheaves. In other respects, low mesostasis and abundant augite, the Talaidh characters are maintained.

The field characters of the two Kielder dikes have been well described by Clough (**8**, p. 20). They are distinguished on the map, fig. 1, as the Kielder Burn and Kielder Viaduct dikes. The latter has been referred to by Thomas and Bailey as a Northumbrian representative of leidleite (**18**, p. 207). In texture the rock is certainly near the leidleite end of the series (pl. II, fig. 1), but it is identical with that of the Crookdene dike (pl. II, fig. 2), and its specific gravity, mineral and chemical composition all show that it is definitely a tholeiite of the Talaidh type. The following micrometric analyses bring out the close resemblance between the Kielder dikes and those of Collywell and Crookdene. It should be noted that in the Talaidh type it is practically impossible to avoid overestimating the pyroxenes at the expense of the mesostasis. For this reason, the felspar ratio in the last column is probably too low.

Mineral proportions of Tholeiites of the Talaidh type.

Dikes.	Mesostasis.	Pyroxene (P).	Felspar (F).	F/(P+F).
344. Collywell ...	23·4	36·4	34·5	49 %
311. Crookdene ...	18·9	37·2	36·6	50
336. Castle Dene ...	27·1	39·2	29·3	43
442. Kittythirst[1] ...	14·7	40·1	34·7	46
460. Windy Knowe[1]	24·2	36·3	28·9	44
310. Kielder Viaduct	19·0	37·1	35·1	49
308. Kielder Burn ...	21·3	34·0	31·8	48

[1] Deadwater north dike.

Chemical composition of the Kielder Viaduct Dike (310).

	Percentages.	Molecular proportions.
SiO_2	51·28	0·8538
Al_2O_3... ...	14·83	0·1455
Fe_2O_3... ...	2·49	0·0156
FeO	5·89	0·0820
MgO	7·45	0·1848
CaO	11·59	0·2067
Na_2O... ...	1·93	0·0311
K_2O	0·66	0·0070
H_2O (+110° C.)	0·91	—
H_2O (−110° C.)	1·41	—
CO_2	0·45	0·0102
TiO_2	0·87	0·0109
ZrO_2	none	—
P_2O_5	0·14	0·0010
Cl	trace	—
S	0·06	0·0019
Cr_2O_3... ...	0·02	0·0001
V_2O_3	0·05	0·0003
NiO	none	—
MnO	0·20	0·0028
SrO	trace	—
BaO	0·01	0·00007
Li_2O	none	—
	100·24	
Less O for S...	0·02	
	100·22	

Specific gravity = 2·87

Norm.		
Quartz		4·94
Orthoclase		3·89
Albite		16·30
Anorthite		29·95
Diopside	$CaSiO_3$ 9·94 $MgSiO_3$ 6·56 $FeSiO_3$ 2·66	19·16
Hypersthene	$MgSiO_3$ 11·98 $FeSiO_3$ 4·88	16·86
Magnetite		3·61
Ilmenite...		1·65
Pyrite		0·12
Apatite		0·34
Calcite		1·02
Chromite		0·02
		97·86
Water		2·32
		100·18

Calculated mineral composition.

Quartz	6·00
Alkali-felspars, $Or_{40}Ab_{60}$ ...	none
Plagioclase, $An_{55}Ab_{36}Or_9$ ...	45·22
Pyroxenes	39·88
Ores (as above)...	5·40
Apatite	0·34
Calcite	1·02
	97·86

Chemical composition.—In order to investigate the Talaidh characters of the Kielder Viaduct rock as completely as possible, a typical sample (310) was selected for analysis. The results indicate that the composition of the rock does not differ in any appreciable way from those of Crookdene and Collywell. In comparison with the Brunton type of the Bingfield dike all three Talaidh types have relatively high CaO and Al_2O_3, and low Na_2O and iron oxides. The first difference is probably to be attributed to the variation from rock to rock in the proportion of anorthite (present either as such or in a reaction product). The second difference is an expression of the fact that in tholeiites having about the same amount of alkali-felspar ($Ab_{60}Or_{40}$), the total Na_2O varies with the total iron oxides. That is to say, Na_2O is proportional to two variables: (*a*) the total iron oxides,

FeO, and (*b*) the alkali-felspar, $Ab_{60}Or_{40}$; the relationship being nearly $6FeO + Ab_{60}Or_{40} = 29Na_2O$, where each constituent is given its percentage value. This point will be referred to again on p. 47.

In the table below, the composition of a Talaidh type of tholeiite from Mull is added. As in some of the other Mull types, Na_2O and iron oxides are higher than in the north of England, and CaO and Al_2O_3 tend to be correspondingly low.

Analyses of Tholeiites of the Talaidh type.

	4. Kielder Viaduct.	G. Crookdene.	H. Collywell.	I. Mull.
SiO_2	51·28	51·31	51·10	53·97
Al_2O_3	14·83	14·55	16·75	14·65
Fe_2O_3	2·49	n.s.d.	n.s.d.	3·62
FeO	5·89	9·02	8·03	6·32
MgO	7·45	6·85	5·89	4·49
CaO	11·59	11·61	11·97	7·98
Na_2O	1·93	1·79	2·02	2·54
K_2O	0·66	0·60	0·66	1·52
H_2O(+110°C.) ...	0·91	1·14	1·16	0·94
H_2O(−110°C.) ...	1·41			1·92
CO_2	0·45	1·47	1·20	0·51
TiO_2	0·87	1·00	0·96	1·24
P_2O_5	0·14	—	—	0·27
S	0·06	—	—	—
FeS_2	—	—	—	0·09
Cr_2O_3	0·02	—	—	—
V_2O_3	0·05	—	—	—
(Co,Ni)O ...	none	—	—	nt. fd.
MnO	0·20	0·47	0·37	0·30
SrO	trace	—	—	—
BaO	0·01	—	—	0·04
	100·24	99·81	100·11	100·40

4. Tholeiite (Talaidh type), Kielder Viaduct dike, Kielder Burn, Northumberland. Analyst, H. F. Harwood (supra, p. 27).
G. Tholeiite (Talaidh type), Crookdene dike, Wansbeck, sixteen miles west of Morpeth, Northumberland. Analyst, J. A. Smythe (**12**, p. 3).
H. Tholeiite (Talaidh type), Collywell dike (= Hartley dike of Teall), Collywell Bay, Northumberland. Analyst, J. A. Smythe (**12**, p. 3).
I. Tholeiite (Talaidh type), basic margin of composite sill, Ruadh a 'Chromain, Mull. Analyst, E. G. Radley (**22**, p. 17).

6. The Acklington Type.

The Acklington dike differs from the others in the north of England in its greater length and continuity and in its uniformity of composition (**2**, p. 242). The Cleveland dike has also a marked petrographic

individuality but is less continuous at the surface. The rock of the Acklington dike (pl. II, fig. 3) is almost devoid of porphyritic crystals or aggregates with anorthite cores, though careful search shows that, though small, they are not entirely absent. Peripheral zoning of the felspar is strongly marked, and forms a broader rim than is usual in other dikes, suggesting a longer period of reaction with the enclosing magma. The dominant mineral is felspar, near labradorite but ranging down to andesine in small haphazardly arranged laths, with no special tendency to clustering about centres. The pyroxenes include rare stumpy prisms of slightly pleochroic enstatite or hypersthene, and an abundant pale grey-green pyroxene which closely resembles the common pyroxene of the Whin Sill and is devoloped in twinned columnar prisms and irregular grains. Streaks and frayed patches of fibrous alteration products generally give the pyroxenes a turbid appearance. Titanomagnetite, fairly well crystallized, is scattered through the rock in small irregular or skeletal individuals. The mesostasis varies considerably in amount from slide to slide. Miss Heslop has noted that the rock becomes richer in glass where it is in contact with the Cheviot andesites (**11**, p. 39). Locally the glass may be biscuit-coloured or brown, in clear and well-defined spaces containing a few skeletal forms and microlites of the prevalent minerals, and the rock then closely resembles the groundmass of the 'glassy' variety of the Eskdalemuir dike described by Tyrrell (**19**, p. 314). Generally, however, the mesostasis is like that of the 'stony' variety of the Eskdalemuir and Muirkirk dikes; that is to say, it is a product of devitrification consisting of a colourless or clouded felsitic base streaked with obscure grey-green shreds of probably chloritic matter and lightly powdered with a globulitic dust of black ores. Amygdales are few and small, and consist of calcite with a thin chloritic lining. According to Topley (**2**, p. 247), chlorophaeite was first detected in England in the Acklington dike, but it has not been found in the specimens we have examined.

The mineral proportions in specimens of the Acklington dike from three localities are given below (p. 30) together with those of other examples of the Acklington type.

It will be noticed that throughout this series the felspars are definitely more abundant than the pyroxenes and that in this respect there is an approach to the Whin Sill type of quartz-dolerite.

Chemical composition.—A representative specimen of the Acklington dike from near Newton (south-east corner of the Cheviots) was

Mineral proportions of Tholeiites of the Acklington type.

Dikes.		Mesostasis.	Pyroxenes (P).	Felspar (F).	F/(P+F)
303.	Acklington	36·8	23·3	33·7	59 %
302.	Newton (Acklington)	24·1	27·5	38·1	58
301.	Clennel (Acklington)	12·7	31·3	42·1	57
481.	Netherton	24·0	28·2	42·6	60
376.	Coley Hill[1] ...	29·8	30·0	35·7	54

[1] The figures refer to the groundmass, which amounts to 92 % of the whole rock, the remaining 8 % being anorthite.

selected for analysis; as the figures of the above table show, its minerals and mesostasis are in approximately average proportions. The rock is markedly richer in silica and poorer in lime and magnesia than the tholeiites already dealt with. Comparison of the calculated mineral composition with the modes shows that the mesostasis contains nearly all the quartz and alkali-felspar together with a varying amount of plagioclase and pyroxene (or their ingredients) in nearly the same proportions as they occur in the crystalline phases. Chemically the rock is thus equivalent to a quartz-dolerite of the Whin Sill type diluted with quartz and alkali-felspar of the composition $Ab_{60}Or_{40}$.

The uniformity of the dike is well shown by analysis J on p. 33, which represents the Moneyacres dike where it crosses Lugton Water (near the Renfrew border of Ayrshire, north of Dunlop). The dike at Lugton is notably richer in titanium dioxide, like some other Scottish representatives of the north of England types, but it is otherwise not significantly different. A specimen of the rock (416) confirms the identity; it is a typical representative of the Acklington tholeiite, differing only in the possession of a higher proportion of titanomagnetite. Another dike, nearer Dunlop, has again the same composition (K, on p. 33). In Mull the only analysed tholeiite of Talaidh type is almost identical in composition with the Acklington dike (G, on p. 28).

The Netherton dike (west of Blyth) has been driven through in the workings of Netherton colliery 420 feet below the surface. It there occurs in two practically vertical sections, 5 and 7 feet thick respectively, separated by 15 feet of dislocated and metamorphosed 'rubble'. The rock is of Acklington type, though somewhat finer in grain than that of the much thicker Acklington dike.

Farther inland the Cross Hollows and Lisle Burn dikes west of Ray Mill are typical Acklington types, with yellowish glass in the latter and easily visible anorthite in the former. Both contain amygdales

Chemical composition of the Acklington Dike (302), near Newton, Northumberland.

	Percentages.	Molecular proportions.
SiO_2	54·67	0·9100
Al_2O_3	13·48	0·1319
Fe_2O_3	3·41	0·0214
FeO	7·26	0·1011
MgO	4·65	0·1153
CaO	8·57	0·1528
Na_2O	2·64	0·0426
K_2O	1·55	0·0165
H_2O (+110° C.)	1·17	0·0650
H_2O (−110° C.)	1·07	0·0594
CO_2	0·38	0·0086
TiO_2	1·35	0·0169
ZrO_2	none	—
P_2O_5	0·19	0·0013
Cl	trace	—
S	0·12	0·0037
Cr_2O_3	none	—
V_2O_3	0·03	0·0002
NiO	none	—
MnO	0·17	0·0024
SrO	trace	—
BaO	0·03	0·0002
Li_2O	trace	
	100·74	
Less O for S	0·04	
	100·70	

Specific gravity = 2·81

Norm.		
Quartz		9·84
Orthoclase		8·90
Albite		22·54
Anorthite		20·36
Diopside	$CaSiO_3$ 7·86, $MgSiO_3$ 4·40, $FeSiO_3$ 3·15	15·41
Hypersthene	$MgSiO_3$ 7·15, $FeSiO_3$ 5·16	12·31
Magnetite		4·86
Ilmenite		2·58
Pyrite		0·24
Apatite		0·34
Calcite		0·90
		98·28
Water		2·24
		100·52

Calculated mineral composition.	
Quartz	10·67
Alkali-felspar, $Ab_{60}Or_{40}$	13·75
Plagioclase, $An_{48}Ab_{42}Or_{10}$	34·27
Pyroxenes	30·67
Ores	7·68
Apatite	0·34
Calcite	0·90
	98·28

with chlorophaeite and calcite, in which respect they show some affinity to the Ray Mill dike.

The Coley Hill dike, exposed near Newcastle-upon-Tyne (**1**, p. 49; **3**, p. 87), closely resembles the Tynemouth dike in the external appearance of its rock, as it contains conspicuous anorthite crystals and aggregates amounting on an average to 8–10 % of the rock. These are zoned with exactly the same peculiarities as those of Tynemouth, but the unzoned internal parts are about An_{94}, which is slightly more calcic than those of Tynemouth. Including the zoned rims the composition of the aggregates cannot be far from An_{90}, as the corresponding Tynemouth figures are An_{90} and An_{85}. The two rocks are also alike in the nature of their amygdales, beautiful examples of the latter filled with partly crystallized mesostasis being common in the Coley Hill dike (pl. II, fig. 4). The body of the

Chemical composition of the Coley Hill Dike (376), near Newcastle-upon-Tyne.

	Percentages.	Molecular proportions.
SiO_2	53·92	0·8978
Al_2O_3... ...	15·81	0·1551
Fe_2O_3... ...	3·05	0·0191
FeO	5·06	0·0704
MgO	5·32	0·1319
CaO	10·22	0·1822
Na_2O... ...	2·09	0·0337
K_2O	1·46	0·0155
H_2O (+110° C.)	1·01	-
H_2O (−110° C.)	1·19	—
CO_2	0·25	0·0057
TiO_2	0·79	0·0099
ZrO_2	none	—
P_2O_5	0·12	0·0008
Cl	trace	—
S	0·06	0·0019
Cr_2O_3... ...	0·01	0·0001
V_2O_3	0·08	0·0005
NiO	none	—
MnO	0·11	0·0016
SrO	trace	—
BaO	0·03	0·0002
Li_2O	trace	—
	100·58	
Less O for S ...	0·02	
	100·56	

Specific gravity = 2·82

Norm.		
Quartz		8·90
Orthoclase		8·62
Albite		17·67
Anorthite		29·59
Diopside	$CaSiO_3$ 7·86 $MgSiO_3$ 5·16 $FeSiO_3$ 2·15	15·17
Hypersthene	$MgSiO_3$ 8·08 $FeSiO_3$ 3·38	11·46
Magnetite		4·42
Ilmenite		1·50
Pyrite		0·12
Apatite		0·27
Calcite		0·57
Chromite		0·01
		98·30
Water		2·20
		100·50

Calculated mineral composition.	
Quartz	9·68
Alkali-felspar, $Ab_{60}Or_{40}$ ...	11·05
Plagioclase,[1] $An_{63}Ab_{27}Or_{10}$ ...	41·22
Pyroxenes	29·47
Ores	6·05
Apatite	0·27
Calcite	0·57
	98·31

[1] Includes about 8 % of An_{90}, the remaining 33 % being approximately An_{56}.

rock, however, is found to be of Acklington type, whereas that of Tynemouth is of Brunton type. A little overlapping of types may be indicated by the restriction to the mesostasis of a considerable proportion of the black ores and an occasional suggestion of stellate clustering by the felspar and pyroxenes. Mineral and chemical analyses, however, confirm the general evidence of the groundmass that the rock is of Acklington type.

Chemical composition.—The analysis of a specimen of the Coley Hill dike containing about 8 % of anorthite aggregates is given above. As will be seen, it differs from the Acklington analysis only in containing more lime and alumina and slightly less silica. That is to say, it represents the Acklington type plus anorthite. Comparison of

this analysis with that of the Hebburn dike (no. 7, p. 40) confirms Teall's conclusion that the Coley Hill dike differs in its characters from those of the Hebburn dike, but comparison with the analysis of the Tynemouth dike (no. 3, p. 23) shows that here there is a greater difference than Teall suspected (**2**, p. 234).

Analyses of Tholeiites of the Acklington type.

	5. Acklington.	6. Coley Hill.	J. Ayrshire.	K. Ayrshire.	L. Arran.
SiO_2 ...	54·67	53·92	54·11	54·56	54·83
Al_2O_3 ...	13·48	15·81	11·65	11·03	14·10
Fe_2O_3 ...	3·41	3·05	2·76	2·87	3·57
FeO ...	7·26	5·06	7·02	6·62	5·87
MgO ...	4·65	5·32	5·30	5·35	4·88
CaO ...	8·57	10·22	8·77	8·98	7·90
Na_2O ...	2·64	2·09	2·63	2·83	2·32
K_2O ...	1·55	1·46	1·75	1·43	1·73
H_2O+ ...	1·17	1·01	0·81	0·88	1·23
H_2O- ...	1·07	1·19	0·68	0·71	0·48
CO_2 ...	0·38	0·25	0·05	0·10	1·90
TiO_2 ...	1·35	0·79	3·37	3·33	0·74
P_2O_5 ...	0·19	0·12	0·58	0·76	0·24
S ...	0·12	0·06	—	—	—
FeS_2 ...	—	—	0·22	0·26	nt. fd.
Cr_2O_3 ...	none	0·01	0·03	0·02	—
V_2O_3 ...	0·03	0·08	—	—	—
(Co,Ni)O	none	none	—	—	0·03
MnO ...	0·17	0·11	0·21	0·23	0·37
SrO ...	trace	trace	—	—	—
BaO ...	0·03	0·03	0·03	0·03	nt. fd.
	100·70	100·56	99·97	99·99	100·19

5. Tholeiite (Acklington type), Newton. Analyst, H. F. Harwood (supra, p. 31).
6. Porphyritic tholeiite (Acklington type), Coley Hill, near Newcastle-upon-Tyne. Analyst, H. F. Harwood (supra, p. 32).

J. Andesitic tholeiite (Acklington type), 60-foot NW. dyke (a continuation of the Acklington-Hawick dike), Lugton Water, 1,000 yards SW. of Smithy, Lugton, Ayrshire. Analyst, B. E. Dixon (**23**, p. 128, no. 800).

K. Andesitic tholeiite, NW. dike, 1¼ miles ENE. of Dunlop, Ayrshire. Analyst, B. E. Dixon (**23**, p. 128, no. 817).

L. Hypersthene-dolerite, holocrystalline equivalent of the basal tholeiite of the Bennan composite sill, shore at foot of Struey Falls, Bennan Head, Arran. Analyst, E. G. Radley, Arran Memoir, 1928, p. 204, no. 12.

Tyrrell's 'Tholeiite (cf. Brunton type), basic member of composite pitchstone-tholeiite dyke, Judd's No. II dyke, Tormore shore, Arran' is chemically a member of the Acklington type. Arran Memoir, 1928, p. 254, analysis no. 21 by E. G. Radley.

The two analyses of the Acklington type are repeated in the preceding table for comparison with some Scottish examples. The only comparable Arran rock which has been analysed is a hypersthene-dolerite representing the holocrystalline equivalent of what elsewhere in the same sill is a typical tholeiite. It is therefore of special interest to find that the mesostasis is stated by Tyrrell[1] to consist of 'alkali-felspar and quartz in micrographic intergrowth'. We have here a definite proof that our deduction of the nature of the Acklington mesostatis from the chemical and mineral analyses is correct.

7. The Cleveland Type.

The Hebburn dike was formerly exposed at Walker and in a quarry near Brockley Whins station which has since been filled up, but at present, as when Teall described the rock, it is to be found in situ only in the workings of Hebburn and Boldon collieries. Superficially the rock is not unlike the Acklington type, and Teall's specimens from the interior of the dike seem to have been of this type (**2**, p. 231). Those that we have examined from the Hutton level are more closely related to the Cleveland type in three respects: the presence of enstatite, the slightly porphyritic character, and the chemical composition. Prisms of colourless enstatite fringed with green alteration products and grains of titanomagnetite are common. There are also long corroded phenocrysts of enstatite-augite mottled with inclusions that may represent altered enstatite (pl. II, fig. 5). Finally there is a grey-green pyroxene sprinkled through the body of the rock in small irregular granules. The felspar laths are haphazardly arranged as in the Acklington type; they are zoned and range from An_{55} to An_{40}. But larger and more equidimensional felspars with well-defined zoned rims are also present, and these are exactly like the still larger felspar phenocrysts of the Cleveland dike. Ores are small but well individualized, and there is an abundant evenly distributed cloudy mesostasis. Amygdales are few and are filled mainly with chalcedony, sometimes with a core of calcite.

The Hebburn dike is the most easterly representative of the linear series which includes the great Eskdalemuir dike of Dumfries, and it is therefore of interest to note that both in mineral development and chemical composition (M, p. 40) there is a striking resemblance between the Boldon and Eskdale rocks. The latter has been described

[1] G. W. Tyrrell, Arran Memoir, 1928, p. 205.

Chemical composition of the Hebburn Dike (380), Boldon Colliery, Co. Durham.

	Percentages.	Molecular proportions.
SiO_2	57·09	0·9505
Al_2O_3... ...	13·76	0·1350
Fe_2O_3... ...	2·74	0·0171
FeO	4·98	0·0693
MgO	4·29	0·1060
CaO	8·12	0·1448
Na_2O	2·51	0·0405
K_2O	1·95	0·0207
H_2O (+110° C.)	1·43	—
H_2O (−110° C.)	1·45	—
CO_2	0·73	0·0165
TiO_2	0·80	0·010
ZrO_2	none	—
P_2O_5	0·13	0·0009
Cl	0·10	0·0028
S	0·03	0·0009
Cr_2O_3... ...	0·01	0·0001
V_2O_3	0·07	0·0005
NiO	none	—
MnO	0·12	0·0017
SrO	none	—
BaO	0·05	0·0003
Li_2O	trace	—
	100·36	
Less O for S and Cl ...	0·03	
	100·33	

Specific gravity = 2·81

Norm.			
Quartz			14·47
Orthoclase			11·52
Albite			20·50
Anorthite			21·05
Diopside	$CaSiO_3$	5·79	11·25
	$MgSiO_3$	3·55	
	$FeSiO_3$	1·91	
Hypersthene	$MgSiO_3$	7·09	10·91
	$FeSiO_3$	3·82	
Magnetite			3·96
Ilmenite			1·52
Pyrite			0·05
Apatite			0·30
Calcite			1·65
Halite			0·08
Chromite			0·01
			97·27
Water			2·88
			100·15

Calculated mineral composition.

Quartz	15·13
Alkali-felspar, $Ab_{60}Or_{40}$ ...	21·40
Plagioclase,[1] $An_{63}Ab_{27}Or_{10}$ ...	28·61
Pyroxenes	24·55
Ores	5·54
Apatite	0·30
Calcite	1·65
Halite	0·08
	97·26

[1] See the reference to this on p. 36.

as the 'Eskdalemuir type of cumbraite' by Tyrrell (**19**, p. 314), who has thus indirectly drawn attention to the relation of the Cumbrae type to the Acklington and Cleveland types, the main distinguishing features of the Cumbrae type being the presence of conspicuous aggregates of anorthite and prismatic crystals of enstatite. If in the future it should be thought desirable to distinguish the rock of the Hebburn dike from the Cleveland type, Tyrrell's term *Eskdalemuir type* is available for its reception.

Chemical composition.—The analysis of a specimen of the Hebburn dike from Boldon colliery is presented above. The higher silica as

compared with the Acklington dike cannot be wholly accounted for by the presence of chalcedony in the amygdales, and is probably to be correlated with the higher percentage of potash. The 'calculated mineral composition' in this case leads to an impossible result for plagioclase (An_{63}), since the actual plagioclase is only An_{55} to An_{40}. Part of the albite of the calculated alkali-felspar must therefore go with the plagioclase, leaving an excess of orthoclase over the $Ab_{60}Or_{40}$ proportion. The composition of the glass of the Cumbrae type has the same characteristic to a marked degree (**19**, p. 309). The presence of chlorine calls for a word of explanation. It occurs in the rock in a soluble form, and is due to the percolation up the walls of the dike of salt water. Stalactites of sodium chloride are common in Boldon colliery workings. The source of the salt is at present unknown.

The Cleveland dike has been previously so fully described (**2**, p. 209; and **6**, p. 60) that it will suffice here to give a brief general description. Of the main mass of the rock two principal varieties may be distinguished according as the mesostasis is vitreous or devitrified. In addition there is a distinctive tachylytic marginal facies which may itself be glassy or stony according to the degree of incipient crystallization within it (**15**); devitrified tachylyte also occurs as small cognate inclusions. In all of these and throughout the whole course of the dike and its marginal offshoots, limpid porphyritic felspars ranging in size up to 1–2 × 3–5 mm. are uniformly distributed, making on an average three or four per cent. of the rock. They vary from idiomorphic to fragmentary and honeycombed forms, inlets and patchy inclusions of mesostasis being common as well as strings of similar material arranged in bands just within the periphery. In the tachylytic facies zoning is not conspicuous but it becomes marked in the normal rock. Teall noted that some of his measurements suggested the presence of a felspar near anorthite, and this has been confirmed by refractive index determinations. Specimens from Bolam (Co. Durham) and Wind Hill (east of Whitby) were found to contain anorthite aggregates approximating to An_{92} and An_{90}, but in these rocks most of the phenocrysts were found to range internally from An_{55} to An_{50}. One of the Bolam felspars, however, gave An_{62}. In specimens from Eaglescliffe, Buckheads, Bowles Beck, Tynehead, Armathwaite, and Dalston all the tested porphyritic felspars fell between An_{55} and An_{50}. Zoning carries the range of composition down to oligoclase. At least two kinds of felspar-phenocrysts are

therefore present in the Cleveland dike, those normal to the rock, ranging from labradorite to oligoclase, and anorthite individuals and aggregates of exactly the same kind as those carried by the tholeiites already described. Anorthite is much more difficult to detect in the Cleveland dike because of its resemblance to the normal phenocrysts in hand-specimens.

Among the larger pyroxenes enstatite is distinctly rare. It has been detected in specimens from Bowles Beck, Woodland Fell, and Armathwaite. Large prisms of colourless to grey-green enstatite-augite or green to brownish-green hypersthene-augite are constant porphyritic elements. As first shown by Miss Heslop (**14**, p. 173) most of these are uniaxial or nearly so, common values of 2V being about 8° to 12° in a range of 0° to 30°. Some of these prisms have an altered fibrous axis which may represent an original nucleus of rhombic pyroxene. The granular augite of the groundmass has a larger optic axial angle and resembles, as far as can be tested, the common augite of the Whin Sill.

The groundmass of the rock is of Acklington type. The felspar laths range from labradorite to oligoclase, but zoning is slight. Occasional stellate groupings with a central cluster of tiny augite-granules may be seen. These are found also in an incipient stage in the marginal facies where the second generation felspars are little more than microliths. It is clear, therefore, that the stellate clusters formed after the main act of injection. There must have been more than one movement of the magma, for irregular inclusions of devitrified tachylyte up to 1 cm. or more are not rare, and the acicular felspars of the margins are often bent or broken.

In some specimens clusters of tiny augites thickly embedded in a sparse felspathic base and accompanied by a few ore individuals form granular colonies ranging in diameter from 1 to 10 mm. (e. g. Dalston, Eaglescliffe, and Barwick). Mesostasis is entirely absent. Barrow has noted that in these remarkable colonies the augite grains do not actually touch one another (**6**, pp. 62–3). It is as if the structures represented a colloidal system—a thin continuous framework of felspathic material serving as a medium for dispersed cells of pyroxene material—which afterwards crystallized.

Titanomagnetite is evenly distributed in idiomorphic and skeletal forms, and grains and shreds of biotite are occasionally to be found moulded on the ores. With regard to the remaining minerals, quartz, apatite, pyrite, alteration products, amygdale infillings (chalcedony

and calcite), and the varied types of mesostasis, it will suffice here to refer to Teall's careful and detailed descriptions (**2**).

The mineral composition of a series of specimens of the Cleveland dike is given in the following table. The figures for felspars refer only to the groundmass and approximately 4 % should be added in each case to allow for the phenocrysts. In the last column the bracketed figures represent the felspar ratio thus corrected.

Mineral proportions of Cleveland and Cumbrae types.

Dikes.	Mesostasis.	Pyroxenes (P).	Felspars (F).	F/(P+F).
Hebburn dike:				
380. Boldon Colliery ...	33·7	23·6	32·7	58 %
Cleveland dike:				
411. Wind Hill ...	39·4	24·7	29·5 (+4)	55 (58)
402. Bolam	34·2	25·3	33·8 (+4)	56 (59)
386. Bowles Beck ...	38·1	22·6	31·3 (+4)	58 (61)
381. Dalston	33·6	26·1	32·9 (+4)	56 (59)
Cumbrae type: [1]				
Eerie Port (glassy) ...	42	22	26	54
Eerie Port (stony) ...	42	20	31	61

[1] Measurements by G. W. Tyrrell (**19**, p. 309). The glassy and stony varieties contain in addition 7 and 10 % respectively of megascopic anorthite.

The Wind Hill rock makes a beautiful section. The mesostasis is a sepia-brown glass becoming clear and colourless around microliths and ores; in consequence, the minerals, which are all fresh, stand out with unusually clean-cut outlines. There is a marked resemblance to the glassy variety of the Eskdalemuir dike. The Bolam rock is the analysed specimen, and in it the mesostasis is almost wholly devitrified (pl. II, fig. 6). The Bowles Beck sections closely resemble the Cumbrae type in all respects save the presence of anorthite.

Chemical composition.—A typical specimen of the Cleveland dike from the quarry in the laccolithic overflow at Bolam gave the following results on analysis. The composition differs in no important respects from that of the Hebburn dike, and the comments made on the calculated plagioclase (An_{63}) in the latter case apply equally here. The Cleveland mesostasis must contain an excess of orthoclase over the $Ab_{60}Or_{40}$ proportion to an even greater extent than that of the Hebburn dike. The very acid character of the glass is proved in a general way by Stock's investigation, recorded in Teall's paper (**2**, p. 224). Unfortunately the alkalis were not separately determined (see E_2, p. 47).

Chemical composition of the Cleveland Dike (402), Bolam, Durham.

	Percentages.	Molecular proportions.
SiO_2	57·57	0·9580
Al_2O_3... ...	13·11	0·1290
Fe_2O_3... ...	3·12	0·0195
FeO	6·60	0·0919
MgO	4·29	0·1064
CaO	7·10	0·1266
Na_2O... ...	2·62	0·0423
K_2O	2·21	0·0235
H_2O (+110° C.)	1·20	0·0667
H_2O (−110° C.)	0·94	0·0522
CO_2	0·28	0·0064
TiO_2	1·24	0·0155
ZrO_2	none	—
P_2O_5	0·19	0·0130
Cl	trace	—
S	0·13	0·0041
Cr_2O_3... ...	none	—
V_2O_3	0·04	0·0003
NiO	none	—
MnO	0·12	0·0017
SrO	none	—
BaO	0·06	0·0004
Li_2O	trace	—
	100·82	
Less O for S ...	0·05	
	100·77	

Specific gravity = 2·77

Norm.		
Quartz		13·23
Orthoclase		13·08
Albite		22·18
Anorthite		17·66
Diopside	$CaSiO_3$ 6·13 $MgSiO_3$ 3·46 $FeSiO_3$ 2·41	12·00
Hypersthene	$MgSiO_3$ 7·22 $FeSiO_3$ 5·06	12·28
Magnetite		4·51
Ilmenite		2·35
Pyrite		0·24
Apatite		0·44
Calcite		0·64
		98·61
Water		2·14
		100·75

Calculated mineral composition.

Quartz	13·95
Alkali-felspar, $Ab_{60}Or_{40}$ ...	27·10
Plagioclase, $An_{63}Ab_{27}Or_{10}$ ...	22·49
Pyroxenes	26·88
Ores	7·10
Apatite	0·44
Calcite	0·64
	98·60

The general uniformity of the dike is proved by the three older analyses (N, O, and P) quoted in the following table. Rocks of the Cleveland type other than those of the north of England have not been analysed, but the Barrmill dike of Ayrshire, described as a quartz-dolerite, is chemically very similar (**23**, p. 128), and so also is a ' basic craignurite ' of Mull (**22**, p. 19).

The Ayrshire dikes which lie on the line of the Cleveland dike are representatives of the Cumbrae type. The NW. dike about six miles east of Ayr has already been recorded by Tyrrell as ' closely resembling the typical cumbraite ' (**19**, p. 313), and this description also applies to specimens of the Barassie and Stevenston dikes (known locally as the ' Caponcraig Gaw ') kindly sent to us by Dr. Tyrrell. Each of these contains zoned crystals and aggregates of anorthite of the same

Analyses of Tholeiites of the Cleveland type.

	7. Hebburn.	M. Eskdale.	8. Bolam.	N. Ayton.	O. Armathwaite.	P. Teesdale.
SiO_2 ...	57·09	58·67	57·57	57·57	58·07	55·19
Al_2O_3 ...	13·76	14·37	13·11	14·25	13·22	12·30
Fe_2O_3 ...	2·74	1·64	3·12	6·04	10·10	10·23
FeO ...	4·98	6·94	6·60	3·95	n.s.d.	n.s.d.
MgO ...	4·29	4·65	4·29	4·24	4·46	4·12
CaO ...	8·12	7·39	7·10	6·87	7·04	7·53
Na_2O ...	2·51	3·01	2·62	2·98	2·59	2·13
K_2O ...	1·95	1·42	2·21	1·08	1·58	1·30
H_2O+...	1·43	2·02	1·20	1·25	1·50	1·55
H_2O-...	1·45		0·94			
CO_2 ...	0·73	—	0·28	0·30	—	3·64
TiO_2 ...	0·80	—	1·24	'trace'	—	1·03
P_2O_5 ...	0·13	—	0·19	0·15	—	—
S ...	0·03	—	0·13	0·19	—	—
FeS_2 ...	—	—	—	—	—	—
Cr_2O_3 ...	0·01	—	none	—	—	—
V_2O_3 ...	0·07	—	0·04	—	—	—
MnO ...	0·12	'trace'	0·12	0·27	—	0·63
SrO ...	none	—	none	—	—	—
BaO ...	0·05	—	0·06	—	—	—
	100·33	100·11	100·77	99·14	98·56	99·65

7. Tholeiite (Cleveland type), Hebburn dike, Boldon colliery, NE. Durham. Analyst, H. F. Harwood (supra, p. 35). Total includes Cl 0·10.

M. Tholeiite (Cleveland type), NNW. dike, Eskdale, Dumfriesshire. Quoted from A. Geikie, Proc. Roy. Phys. Soc. Edinburgh, 1880, vol. 5, p. 253. See also 'Ancient volcanoes of Great Britain', 1897, vol. 2, p. 137.

8. Tholeiite (Cleveland type), Cleveland dike at Bolam quarry, Co. Durham. Analyst, H. F. Harwood (supra, p. 39).

N. Cleveland dike, Great Ayton, Yorkshire. Analyst, W. F. K. Stock, quoted from Teall (**2**, p. 224, and **5**, p. 206).

O. Cleveland dike, Armathwaite, Cumberland. Analyst, W. F. K. Stock, quoted from Teall, loc. cit.

P. Tachylyte border of the Cleveland dike, junction of Tees and Lune, near Middleton-in-Teesdale. Analyst, R. C. Burton (**15**, p. 61).

kind as those of the Great Cumbrae, Coley Hill, and Tynemouth dikes. These Ayrshire dikes may therefore be regarded as a link between the Cleveland dike and those of the Great Cumbrae (**19**, p. 313) and the Cowal peninsula (Cumbrae types) of Argyllshire.[1] Along the seaboard of Argyll tholeiite dikes appear to be common and one of these, near Easdale, is of Cleveland type,[2] judging from the published

[1] Mem. Geol. Surv. Scotland. The geology of Cowal, 1897. pp. 130 et seq. See also, The geology of mid-Argyll, 1905, p. 119.

[2] The geology of the seaboard of mid-Argyll, 1909, p. 87, and pl. 8, fig. 2.

description. In Mull the nearest approach to the Cleveland type is inninmorite (**18**, p. 209).

Nomenclature.—It may be questioned whether it is justifiable to extend the term tholeiite to include the Acklington and Cleveland types, as in this paper, and the Cumbrae type, as in the Arran Memoir (p. 253). In these three types the F/(P + F) ratio ranges from 54 to 61, whereas in the Salen, Brunton, and Talaidh types, the range is from 41 to 50.[1] The apparent gap, however, has no real existence, for, as stated already, the Talaidh ratios are certainly too low, and the analysed Talaidh tholeiite of Mull has the same composition as the Acklington type. No natural line can anywhere be drawn which would limit the tholeiite series in such a way as to exclude any of the types under consideration. Chemically the rocks lie between Loewinson-Lessing's[2] andesito-basalt ($a = 2{\cdot}16$, as in the Cleveland type) and basalt ($a = 1{\cdot}70$, as in the Salen and Brunton types).[3] There can therefore be no objection to distinguishing 'andesitic tholeiites' from the tholeiites proper on arbitrary chemical grounds. This has already been done by the Survey (**23**, p. 128), and it may be regarded as symptomatic of a growing tendency to use the term tholeiite generically without restricting its utility by a too-precise specific definition. The real difficulty in arriving at a satisfactory naming of the tholeiites in terms of the usual nomenclature is that the suite as a whole is made up of four distinct classes of material: (*a*) anorthite crystals and aggregates; (*b*) framework of basaltic minerals; (*c*) iron-rich mesostasis; and (*d*) quartz-alkali-felspar mesostasis. It is only in its reference to the bulk composition when the last of these is abundant that the qualifier 'andesitic' has any special significance. The erection of specific types, each precisely defined, within the general field of the tholeiite series seems to be the only way of avoiding confusion.

8. Relationships and Genetic Considerations.

Distribution.—It is a remarkable feature that wherever Tertiary tholeiites occur several different types are to be found in proximity. This contrasts strikingly with the lack of variation of the quartz-

[1] The ratio for the measured specimen of the Barrington dike (p. 20) is 52, but is not typical, as the rock is transitional to the Acklington type.

[2] F. Loewinson-Lessing, On the delimitation of the families of basalts and andesites. Bull. Com. Geol. U.R.S.S., 1925, p. 411 (English abstract, p. 420).

[3] The Whin Sill type of quartz-dolerite has $a = 1{\cdot}72$.

dolerites (**26**, p. 530). It is true of Mull, Argyll, Ayrshire, Arran, and Bute, and of the type area, the Nahe district of Germany. The following diagram (fig. 3) brings out the peculiarities of distribution in the north of England. The capital letters refer to the initials of the type-names, S being used for all olivine-bearing types.

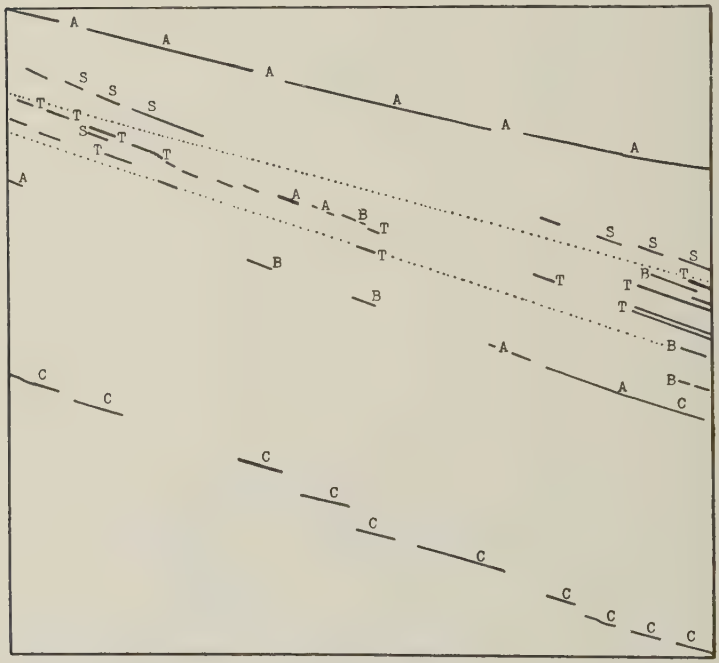

Fig. 3. Diagram illustrating the distribution of types among the tholeiite dikes of the north of England. For localities see fig. 1.

The distribution is clearly not entirely haphazard. The thick Acklington and Cleveland dikes maintain their individuality throughout the region studied. With one exception Salen types (including olivine-bearing Brunton types) are restricted to a single echelon series; and Talaidh types to the dotted belt. Traced farther across Scotland thick dikes of Acklington type become predominant until the coastal region of Ayrshire is approached; there olivine-bearing and anorthite-bearing types also become common. It is noteworthy that while thin dikes may be of any type, the thicker dikes are always of Acklington or Cleveland types.

Until the details of distribution have been determined throughout the whole belt up to its focus in Mull any attempt at an explanation would be premature. The magma of the underlying source may have varied longitudinally, transversely, and in depth. It was probably streaky in composition and gas content, and it may have extended over an area far greater than that to which the dikes are confined. The unknowns are at present too many for deductions from surface samples to be drawn with any confidence. The relation to Mull, however, suggests the hope that sooner or later the distribution of dikes will help to elucidate the nature of the currents and other processes that determine or accompany igneous activity of the central type.

Anorthite aggregates.—Practically all the Tertiary tholeiites can be shown to contain anorthite, and locally the mineral is abundant. The problem of origin has been discussed by Teall (**7**, p. 482), Miss Heslop and Smythe (**12**, p. 16), and Harker.[1] The phenomenon is not an isolated one. Anorthite lumps thickly covered with flakes of graphite occur in the iron-bearing basalt of Uifak, Greenland, and in certain other basalts of Disko Island.[2] Quasi-porphyritic crystals and aggregates of anorthite occur in some of the dolerite dikes and sheets of Skye and Mull, and very small examples are to be found in the Whin sill and its related dikes (**26**, p. 502). The anorthite may have been

(*a*) picked up from troctolites, eucrites, or other anorthite-bearing rocks transversed by the magma;

(*b*) produced by interaction of magma and aluminous sediments, as has occurred in Mull;[3] or

(*c*) produced at an early stage from the parent magma of that which later gave rise to the enclosing rock.

In case (*a*) other minerals should be present, as in the glomeroporphyritic patches of olivine and anorthite in the dolerite of Fair Head, Antrim.[4] Moreover, if the anorthite had been broken from a rock previously in existence, it is difficult to understand why rock fragments of other kinds should be entirely missing. In case (*b*) there should be evidence of the presence of corundum or spinel, as in Mull (**22**, p. 276). In the north of England no evidence of either class has

[1] A. Harker, Tertiary igneous rocks of Skye, 1904, p. 362.

[2] O. B. Bøggild, Mineralogia Groenlandica, Kjøbenhavn, 1905.

[3] H. H. Thomas, Certain xenolithic Tertiary minor intrusions in the Island of Mull. Quart. Journ. Geol. Soc. London, 1922, vol. 78, p. 229.

[4] J. W. Judd, Quart. Journ. Geol. Soc. London, 1886, vol. 62, p. 71, and pl. 7, fig. 3.

ever been detected despite most careful search, and like earlier investigators we are driven to adopt hypothesis (*c*) as the most probable. The existence of an early magma from which rocks containing anorthite could crystallize is supported by ample evidence in Skye and Mull and other Tertiary centres. In his investigation of the rocks of Mont Pelée, Lacroix[1] describes phenocrysts in andesite which are dominantly An_{45}–An_{52}, with a central core of An_{92}–An_{95}. The grouped phenocrysts of miharaite (Ōshima, Japan) have alternate zones, of which the more calcic members are An_{87}.[2] Comparison between the lavas of 1912 (in which the phenocrysts occur) and the older comagmatic lavas suggests to Tsuboi that 'as the cooling of the magma proceeded, olivine, pyroxene, and plagioclases separated out in the magma basin. Of these minerals, the last one, matching the magma closely in density, remained practically suspending in the magma basin; while the other two, being much heavier than the magma, sank down'.[2]

It seems likely that some such process led to the isolation of the anorthite found in the tholeiite dikes, but some other factor or factors at present unknown must have been involved to make possible the sudden break in composition between the original anorthite and the zoned rim. It may be that in the presence of abundant iron oxides the normal crystallization of albite in plagioclase is deferred. Notwithstanding our ignorance of the actual conditions it seems safe to refer the anorthite to an early stage of the magmatic history. Presumably the dike-area was either a belt of low vertical pressure (at magmatic levels) towards which magma was squeezed from bordering regions of greater pressure, or a belt in which the internal bursting pressure rose by local accumulation of volatiles.[3] In either case the anorthite aggregates would tend to collect in roof corrugations and to be drawn into streaks as a result of differential viscous flow. Once the stress differences rose sufficiently to shatter the overlying rocks, dikes locally enriched in anorthite would be formed wherever a particular fissure tapped an accumulation of anorthite, or wherever an injection current carried up an anorthite-rich streak. Every dike

[1] A. Lacroix, La Montagne Pelée et ses éruptions, Paris, 1904, p. 505; see also J. Stansfield, Assimilation and petrogenesis, Urbana, Ill., U.S.A., 1928, pp. 80–81.

[2] S. Tsuboi, Notes on miharaite. Journ. Geol. Soc. Tokyo, 1918, vol. 25, p. 47. [Min. Abstr., vol. 1, p. 209.]

[3] G. W. Morey, The development of pressure in magmas as a result of crystallization. Journ. Washington Acad. Sci., 1922, vol. 12, p. 219.

would have traces of anorthite on this hypothesis, but the distribution of the richer patches would be quite haphazard.

Magmatic variation.—The most suitable analyses to employ for the construction of a variation diagram are those of Bingfield (Brunton), Coley Hill (Acklington), and Hebburn (Cleveland), for they lie on a single line of dikes and exhibit almost a maximum range of composition. The Coley Hill rock is abnormal in its content of anorthite,

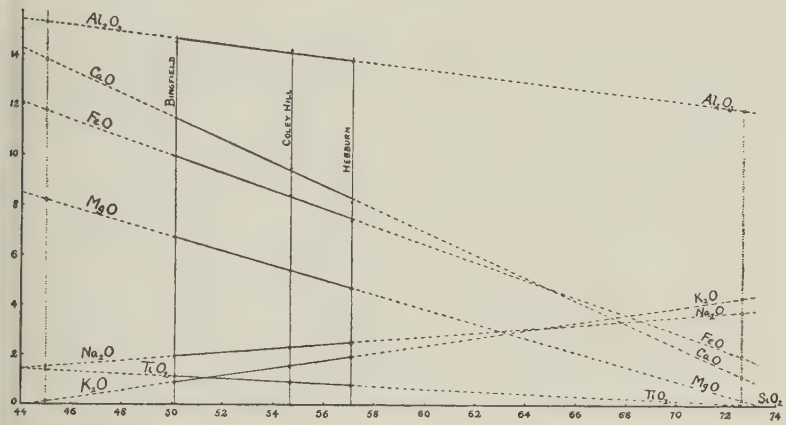

Fig. 4. Linear variation-diagram of the Bingfield–Coley Hill–Hebburn dike-system.

but, as the presence of the latter is accidental, comparison of the magma of this rock with those of the others can be fairly made only after 8 % of anorthite has first been subtracted from the bulk composition.

This has been done, using Smythe's analysis of the Hartley anorthite (p. 25) to represent the optically identical Coley Hill anorthite. The resulting composition of the body of the rock is plotted in fig. 4 with the other two analyses, and, as shown, the figures make a straight-line diagram. Although not inserted, the Kielderhead and Tynemouth (less anorthite) analyses also fit the Bingfield end of the diagram. The composition C of any rock in this series can therefore be expressed as $C = B + nE + mA$, where B is the composition of the Bingfield rock; E is a quartz-alkali-felspar 'end product'; A is anorthite; and n and m are constants for any given rock.

The Acklington and Cleveland analyses, together with some of the Scottish representatives, systematically fail to fit this straight-line diagram by having low CaO and Al_2O_3. Relative deficiency of

anorthite is thus disclosed, but there is no way of estimating the deficiency, and consequently the analyses cannot be accommodated in the diagram as those of Coley Hill and Tynemouth have been. The straight-line diagram implies uniform variation between the Bingfield rock (the basaltic framework plus the iron-rich mesostasis) on the one hand, and a quartz-alkali-felspar mesostasis on the other. Superimposed on this, the simplest case, we have at least two other possible variables: (*a*) the irregular distribution of anorthite already referred to; and (*b*) variation in the proportion of the iron-rich mesostasis, or in the proportion of iron oxides within it. It is in consequence of (*b*) that the Talaidh analyses (and also the Acklington analysis) would depart from straight-line variation even if (*a*) could be allowed for.

Returning to the analyses that do conform to straight-line variation we can apply the data on fig. 4 to determine roughly the composition of E. Obviously it may lie anywhere to the right of the line representing the Hebburn analysis. The composition of the Hebburn mesostasis can be estimated by subtracting from the bulk analysis the estimated composition of the basaltic framework. This clearly shows that E is mainly quartz plus alkali-felspar near $Ab_{60}Or_{40}$, and that the silica percentage is between 72 and 76. Adopting $SiO_2 = 72{\cdot}66\,\%$, we read off the composition given below under E_1. For comparison E_2 is added, representing an approximation to the base of the Armathwaite dike. The felspar of E_1 is $Or_{42}Ab_{54}An_4$, which corresponds in type exactly with that of Vogt's 'ternary eutectic'. In 1921 Vogt deduced $Or_{42}(Ab + An)_{58}$ from the evidence then available,[1] but in 1926, as a result of a more detailed study, he adopted $Or_{40}(Ab + An)_{60}$.[2]

A magma of Coley Hill or Hebburn composition could be produced from one of Bingfield composition not only by the addition of material like E_1 but also by subtraction of material like C_1. The composition of C_1, as shown in the table below, differs beyond all possibility of error from the composition of the crystalline phase C_2, that actually did separate from the Bingfield magma. If the latter had been able to free itself from crystals it would have changed in the direction of trachybasalt. It is probably because this kind of process has operated

[1] J. H. L. Vogt, Journ. Geol. Chicago, 1921, vol. 28, p. 339, table IV.

[2] J. H. L. Vogt, The physical chemistry of the magmatic differentiation of igneous rocks. II. On the felspar diagram Or : Ab : An. Skrifter Norske Vidensk. Akad. I. Mat.-Nat. Kl. Oslo, 1926, no. 4, pp. 84 and 101.

	E_1.	E_2.	C_1.	C_2.	M.
SiO_2 ...	72·66	70·76	45·0	51·1	49·1
Al_2O_3 ...	11·94	10·93	15·3	15·2	13·0
FeO ...	2·00	3·59	11·8	9·0	11·5
MgO ...	0·20	4·21	13·8	7·6	4·9
CaO ...	1·18	3·29	8·2	12·4	9·8
Na_2O ...	3·80	7·22	1·5	1·9	2·0
K_2O ...	4·32		0·1	0·5	1·7
TiO_2 ...	—	—	1·4	—	3·3

E_1. From fig. 4 at $SiO_2 = 72·66$ %.

E_2. Composition of insoluble residue from the Armathwaite dike. Analyst, W. F. K. Stock in **2**, p. 224.

C_1. Composition of a hypothetical crystalline differentiate, from fig. 4 at $SiO_2 = 45·0$ %.

C_2. Estimated composition of the crystalline phase of the Bingfield dike.

M. Estimated composition of the mesostasis (including ores) of the Bingfield dike. Calculated by subtracting C_2 from the bulk analysis of the rock (p. 18).

to a very limited extent that the soda varies with the proportion of iron oxides as well as with that of the 'end-product', E.

The association of iron oxides and soda is of particular interest in connexion with the genesis of alkali-rocks, as it suggests a means whereby residual magmas unsaturated in respect of both silica and alumina might be generated. It is possible, as already suggested on p. 44, that early anorthite may crystallize with less than the normal amount of albite because of the withholding of soda in the presence of abundant iron oxides. If for any reason the soda-iron-rich residuum were to be strained away from the anorthite it would constitute a magma in which soda and iron oxides could combine with silica and so provide the conditions necessary to the production of alkali-rocks. It should be noted that in quartz-dolerites and tholeiites relatively little of the iron occurs as silicate; if most of it had joined with silica the rocks would not have been oversaturated. In the Brunton tholeiites we see a process of differentiation of exactly the same kind as was observed in a basalt flow in Mozambique.[1] In the Brunton example the reaction of the magma with anorthite already produced has hidden the tendency towards alkalinity; in Mozambique, on the contrary, the associated rocks are tephrite and phonolite.

Separation of M and C_2 has certainly not operated in generating the tholeiite suite of the north of England. To produce from the

[1] A. Holmes, The Tertiary volcanic rocks of the district of Mozambique. Quart. Journ. Geol. Soc. London, 1917, vol. 72, p. 243.

magma of the Bingfield rock a more acid type of tholeiite it would be necessary to withdraw material having the composition of C_1. This represents an assemblage of constituents which it has not been possible to match with any known rock. We may therefore deduce that differentiation by crystallization and separation of the residual liquid was not the process involved in the production of the different types of tholeiites. This follows even more convincingly from the haphazard distribution of anorthite, and from the implication of the straight-line diagram.[1]

The mineral assemblage of the rocks further supports the conclusion. As shown in our Whin Sill paper (**26**, p. 507), in rocks formed by the consolidation of successive residual magmas produced from basalt by crystallization-differentiation, the pyroxenes would not be expected to begin afresh in each successive rock with hypersthene. This argument suggests that hypersthene-andesites may be basic representatives of a 'sial' magma, or a consequence of assimilation of aluminous sediments, but not residual products from an uncontaminated basaltic magma.[2] Our Cleveland and Acklington types, however, are not andesites. Their crystalline framework is typically basaltic. The felspar ratio F/(P + F) reaches but does not exceed the corresponding figure for the Whin Sill, and is generally lower, whereas in a residual product a higher value would be expected. The anorthite-content of the plagioclase does not fall with the rise of the felspar ratio as would be expected on the hypothesis of crystallization-differentiation.[3] Similarly, the normative pyroxene ratio MgO/(MgO + FeO) in the Cleveland and Acklington dikes (0·59 and 0·58) is as high as in the Bingfield dike (0·58), while in the Coley Hill and Hebburn dikes the ratio is actually very much higher (0·71 and 0·72). All are higher than the Whin Sill value (0·52). The tholeiites thus behave as basaltic rocks which in some cases have been merely diluted with the quartz-alkali-felspar material, *E*.

In further accordance with this conclusion is the important fact that the Whin Sill type of magma is generally characterized by widespread regional constancy. It does not, in its most spectacular developments, differentiate towards the possibility of rocks like those of Acklington and Cleveland types. Why then should the very similar

[1] C. N. Fenner, The Katmai magmatic province. Journ. Geol. Chicago, 1926, vol. 34, pp. 765 et seq.

[2] See Footnote 3 on pp. 49–50.

[3] J. H. L. Vogt, Journ. Geol. Chicago, 1921, vol. 29, p. 427.

magma of the Brunton type readily appear to do so ? The only significant difference is the greater content of volatiles in the Brunton-type magma, but even this cannot be assumed for the magmas of the Acklington and Cleveland dikes. Abstraction of material of type E from one part of a magma and its concentration in another by gaseous transfer is evidently not a process that can be assumed in our problem, for volatiles are commonly low where E is greatest, and dikes in which E is negligible come to a head in a confusion of carbonates through which textural relics still testify to an original composition like that of the depths of the dike (**12** and **17**). Moreover, gaseous transfer, if one may judge from the assemblage of lavas found in oceanic volcanoes, leads to the trachybasalt-trachyte association of rocks. Tholeiites, like quartz-dolerites (**26**, p. 541), are continental rocks and have no place in oceanic islands.

There remains the possibility that the Brunton-type magma changes towards E not as a result of differentiation but by selective assimilation of material of composition E_1 or by admixture with a coexisting magma of composition E_1. The magma most easily formed from 'sial' heated up by its long-continued contact with a basaltic magma would presumably be one corresponding closely to the ternary eutectic of quartz, albite, and orthoclase. It would be idle to speculate as to the precise way in which magmatic mixing might occur, for there are many plausible possibilities. Our study, however, finally leads to the belief that there is no satisfactory alternative to the assumption of mixing by one process or another. Similar arguments apply to many of the puzzling rocks of Mull, such as inninmorite and the rocks of the 'differentiation column' (**22**, p. 320); to the common association of rocks of strongly contrasted composition in composite dikes and sills in Mull and other Tertiary centres;[2] and indeed, to all provinces in which gabbros, dolerites, and basalts, on the one hand, occur dominantly with granites, granophyres, quartz-porphyries, and rhyolites, on the other, without any noteworthy development of intermediate types.[3] The restriction of all such associations to the

[1] For a recently described case of this kind, see D. R. Grantham, Proc. Geol. Assoc. London, 1928, vol. 39, pp. 327 et seq.

[2] E. M. Guppy and L. Hawkes, Quart. Journ. Geol. Soc. London, 1925, vol. 81, p. 325; and H. K. Cargill, L. Hawkes, and J. A. Ledeboer, ibid., 1928, vol. 84, p. 505.

[3] In the second of the papers referred to above a 'quartz-diorite' from the Vestur Horn intrusion in south-east Iceland is described (p. 513). It contains both potash-felspar and plagioclase, and hypersthene is present. The authors

continents (or to areas like Iceland which for isostatic and seismological reasons are assumed to be underlain by 'sial') is strong evidence that they are the product, not of basaltic magma alone, but of both basaltic and granitic magmas generated in their respective 'sima' and 'sial' levels. If it be agreed that crystallization-differentiation and the idea of immiscible separations from a parent intermediate magma alike fail to explain this characteristically Tertiary and continental assemblage of rocks, then the long-despised conception of Bunsen[1]—that *two* fundamental magmas, basic and acid, are the parents of all the igneous rocks of Iceland and similar provinces—again becomes worthy of serious attention.

9. Acknowledgements.

Our thanks are due (on behalf of Dr. Harwood) to Prof. H. B. Baker for providing facilities in the laboratories of the Imperial College, for carrying out the analytical work; and (on behalf of Dr. Holmes) to Lady Teall for the gift of many of the specimens collected and studied by Sir Jethro Teall in the course of his work on the north of England dikes; to Dr. G. W. Tyrrell for many specimens of related Scottish dikes and for much helpful discussion during the course of the work; to Dr. Stanley Smith for placing at our disposal his unrivalled knowledge of the Cleveland dike, and for a collection of specimens adequately representing the dike from end to end; to Mr. G. S. Mockler for opportunities of studying and discussing the collections in his charge at Armstrong College; to Dr. W. Hopkins for helpful co-operation in the field; and to the Managers of Boldon, Cowpen, and Netherton Collieries for their kindness in supplying samples and particulars of the dikes running through their respective workings.

Explanation of Plate I.

Magnification ×20. Ordinary light.

Fig. 1. *Olivine-tholeiite* (Salen type). Kielderhead dike, Northumberland (no. 306). The field shows partly serpentinized olivine, near the centre; the characteristic ophitic relations between augite and plagioclase; and the relatively small proportion of mesostasis. Description, pp. 12–13. Analysis, p. 15.

Fig. 2. *Olivine-tholeiite* (olivine-bearing Brunton type). Peel Burn dike, Roxburghshire (no. 478). This differs from fig. 1 in the higher proportion of

remark, 'The patchy distribution of the dark minerals in this rock is strongly suggestive of admixture.' On p. 533, however, they assume the extreme magmas to be products of *differentiation* operating during the igneous cycle.

[1] R. W. Bunsen, Ann. Phys. Chem. (Poggendorff), 1851, vol. 83, pp. 197–272.

mesostasis and the clustering of the minerals. Olivine, being almost wholly serpentinized in this field, is not easily distinguished from the mesostasis. Description, p. 13.

Fig. 3. *Tholeiite* (Brunton type) from the type locality, Bingfield dike, Redhouse Burn, Northumberland (no. 369). Plagioclase and pyroxene are segregated into stellate clusters, 'partly in contact with one another, partly separated by mesostasis'. Description, p. 17. Analysis, p. 18.

Fig. 4. *Tholeiite* (anorthite-bearing Brunton type). Tynemouth dike, Northumberland (no. 356). The field is selected to illustrate one of the smaller quasi-porphyritic crystals of anorthite with fretted edges and inclusions. Description, p. 20. Analysis, p. 21.

Fig. 5. *Tholeiite* (Brunton type). Ray Mill dike, Northumberland (no. 340). Part of the dark background is brownish-green chlorophaeite. Description, pp. 19–20.

Fig. 6. *Tholeiite* (Brunton type). Warksburn dike, Northumberland (no. 363). The field shows the typical Brunton texture and a calcite amygdale. Description, p. 19.

Explanation of Plate II.

Magnification × 20. Ordinary light.

Fig. 1. *Tholeiite* (Talaidh type). Kielder Viaduct dike, Northumberland (no. 310). The texture is finer than in the Brunton type and sheaf-like bundles of pyroxene largely take the place of granular aggregates. Description, p. 26. Analysis, p. 27.

Fig. 2. *Tholeiite* (Talaidh type). Crookdene dike, Northumberland (no. 311). The texture is identical with that shown in the preceding figure, but is broken by four small amygdales. The top one (*a*) is filled with chlorophaeite, chalcedony, and quartz. The other three, in order, from left to right, are occupied by (*b*) mesostasis; (*c*) mesostasis followed by calcite and chlorophaeite; (*d*) chlorophaeite and calcite.

Fig. 3. *Tholeiite* (Acklington type). Acklington dike, near Newton, south-east corner of the Cheviots, Northumberland (no. 302). Here the felspars are in broader laths and the pyroxenes are characteristically granular. Description, p. 29. Analysis, p. 31.

Fig. 4. *Tholeiite* (anorthite-bearing Acklington type). Coley Hill dike, near Newcastle-upon-Tyne (no. 376). The field illustrates the body of the rock (anorthite not being shown) and includes an excellent example of a mesostasis-filled amygdale. Description, p. 31. Analysis, p. 32.

Fig. 5. *Porphyritic tholeiite* (Cleveland type). Hebburn dike, Boldon colliery, Co. Durham (no. 380). The field shows phenocrysts of plagioclase and pyroxene in a groundmass of Acklington type. Description, p. 34. Analysis, p. 35.

Fig. 6. *Porphyritic tholeiite* (Cleveland type). Cleveland dike, Bolam quarry, Co. Durham (no. 412). A small porphyritic crystal of pyroxene and part of a corroded phenocryst of plagioclase with inlets and inclusions of mesostasis are shown in a groundmass of Acklington type. Description, p. 36. Analysis, p. 39.

Acknowledgements. With the exception of figs. 3 and 4, plate I, which are the work of Mr. G. S. Sweeting, of the Geology Department of the Imperial College, the photomicrographs here reproduced were prepared by Mr. G. O'Neill, of the Geology Department of the Durham Colleges, from thin sections which, together with a large number of others, were also made for this investigation by Mr. O'Neill. For the willing and efficient services thus rendered we desire to add a special word of acknowledgement and thanks.

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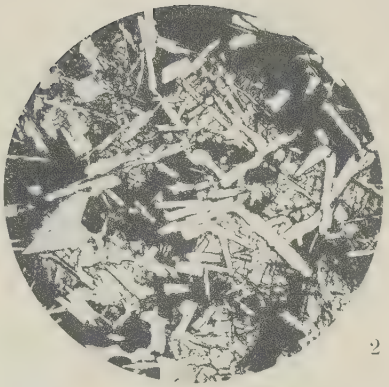
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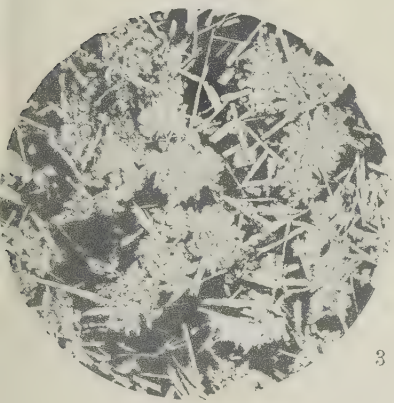
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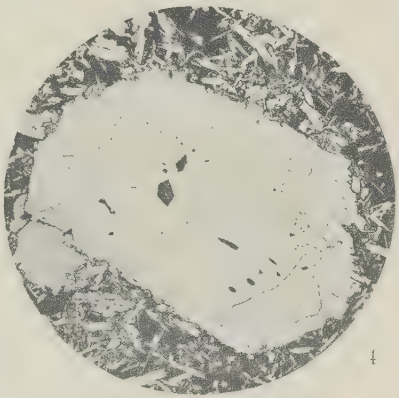
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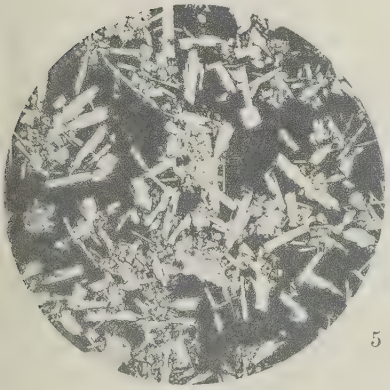
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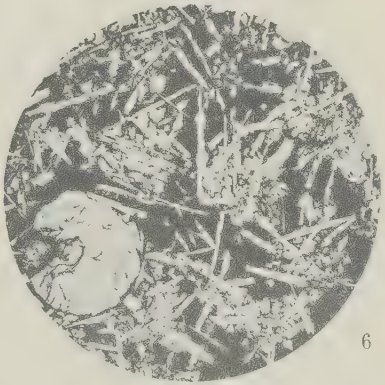
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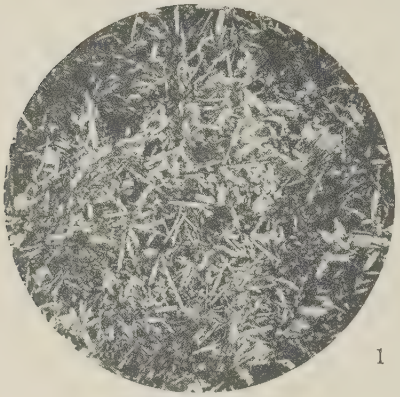
A. Holmes and H. F. Harwood: Tholeiite Dikes of the North of England.



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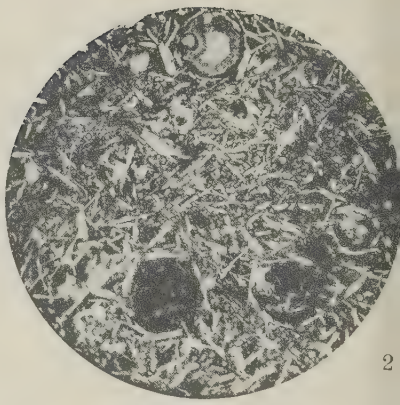

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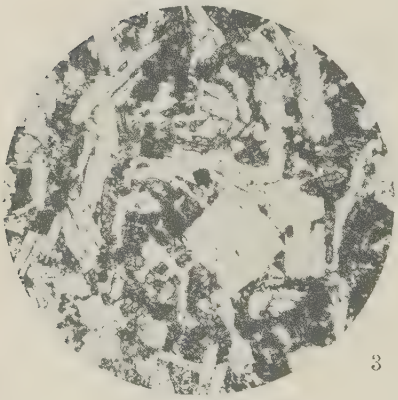

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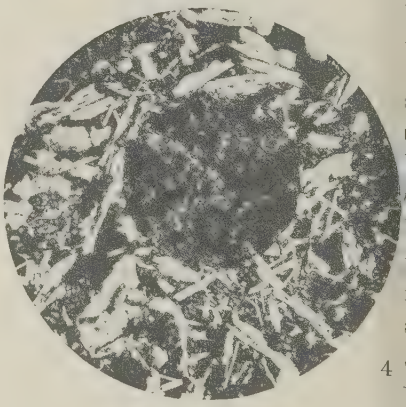

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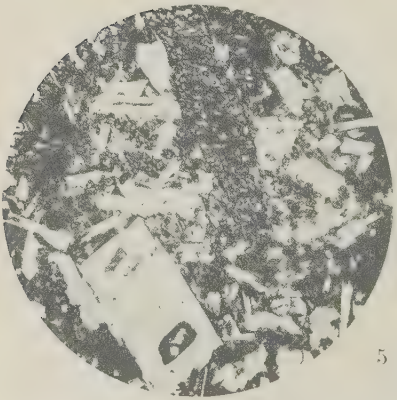

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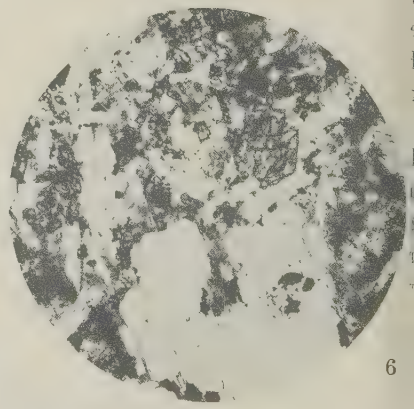

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A. Holmes and H. F. Harwood: Tholeiite Dikes of the North of England.

The so-called 'thermokalite' and the existence of sodium bicarbonate as a mineral.

By F. A. Bannister, M.A.

Assistant-Keeper in the Mineral Department of the British Museum (Natural History).

[Read November 6, 1928.]

In a brief account of the Johnston-Lavis collection of Vesuvian minerals, now preserved in University College, London, Dr. K. W. Earle mentions 'a large number of specimens of "Thermokalite", a new member of the Haloid group, which has, apparently, so far escaped description.'[1] This previously unpublished name was copied from Dr. Johnston-Lavis's manuscript labels. The late Dr. H. J. Johnston-Lavis (1856–1914) possibly considered that this mineral was the potassium compound corresponding to thermonatrite [$Na_2CO_3.H_2O$]. A provisional name for an undetermined mineral having, in this way, unfortunately been published, it seemed desirable to clear up the matter. For this purpose Dr. Earle very kindly supplied two good specimens of the mineral for investigation. Access was also given to the note-books kept by Dr. Johnston-Lavis. He had made a separate entry for each specimen and the carbon copies were placed with the specimens. The entry for 'thermokalite' reads in every case: 'Thermokalite (n. sp.) by Tunnel nr. Stufe di Nerone, Baja.' This locality is situated about nine miles west of Naples in the Phlegrean Fields (Campi Phlegraei).

The name 'thermokalite' is not mentioned in the bibliography of Dr. Johnston-Lavis,[2] but a reference to the incrustations is made in a report to the British Association for the Advancement of Science in the year 1889. Dr. Johnston-Lavis acted as secretary to the committee which presented eleven reports on the investigation of the volcanic phenomena of Vesuvius and its neighbourhood to the British

[1] K. W. Earle, Proc. Geol. Assoc. London, 1928, vol. 39, p. 96. The name 'thermokalite' has been listed in Min. Mag., 1928, vol. 21, p. 578.

[2] H. J. Johnston-Lavis, Bibliography of the volcanoes of southern Italy. London, 1918.

Association during the years 1885–95. Reference is made in the report for 1886 (p. 228) to plans for the Cumana railway which was to connect Naples with Baia and Fusaro. The new railway would necessitate tunnelling the hill which backs Baia. In the report for 1888 (p. 322) it is noted that the entrance of this tunnel had been commenced just beneath the Baths of Nero (Stufe di Nerone) and considerable difficulties were anticipated owing to the high temperature of the rock. A full account of the tunnelling operations is given in the 1889 report (pp. 289–91). During excavations many cuniculi cut out by the Romans were found. These cuniculi are underground conduits just large enough to allow a man to pass, and were apparently made for the passage of the thermal spring water to the baths. In one of the principal cuniculi Dr. Johnston-Lavis found abundant saline incrustations varying from 1 to 10 cm. in thickness. These covered the walls of the tunnel for a considerable distance; under the incrustations a light brown friable tuff was found. The conditions of temperature and atmosphere had, of course, been affected by the increased ventilation afforded by excavation. However, the temperature observed in the principal cuniculus was 73° C., and Dr. Johnston-Lavis attributed the distressing physiological condition of his guide and himself after visiting this tunnel to the presence of considerable carbon dioxide in the atmosphere. Dr. Johnston-Lavis concluded from qualitative tests on these saline incrustations that the principal component was potassium carbonate. He observes that this salt appeared to be present in 'two, if not three different varieties of hydration'. He also found sodium present and small quantities of chloride and sulphate. Although it will be shown that these results are not confirmed by the present paper, there can be no doubt that the series of specimens labelled 'thermokalite' in the Johnston-Lavis collection are the incrustations that were collected and examined by Dr. Johnston-Lavis prior to this report of 1889.

A considerable quantity of the incrustation must have been collected, for we find 'thermokalite' very well represented in the Johnston-Lavis collection. About a dozen large specimens are shown in the case-tops. The largest and most beautiful of them measures approximately $30 \times 24 \times 6$ inches; the remainder average about one-third of this size. Still smaller but quite excellent specimens are stored in two cabinet drawers.

The two specimens handed over for examination are about the size of one's fist, and consist of a snow-white friable material with some

pale yellow stains in places. There is no rocky matrix present on these specimens, but on one or two of the incrustations in the Johnston-Lavis collection the 'thermokalite' is covered on one side with a light brown powdery tuff. The surface of the two blocks is cavernous, but the interior is more compact and shows a fibrous structure. Bundles of minute needles line the cavities, and a preliminary microscopic examination of these crystals revealed the presence of thermonatrite and trona. The material dissolves readily and completely in cold water. Qualitative tests showed the presence of sodium sulphate and carbonate, a trace of iron, but no potassium or ammonium salts. No trace of a chloride could be detected; the addition of silver nitrate to a solution of about three grams of the material in nitric acid produced only a faint turbidity. It was thought that the crusts might vary in composition. Dr. K. W. Earle, therefore, kindly allowed me to take small specimens, each about five grams, from several other crusts in the Johnston-Lavis collection, for the detection of potassium. The most careful tests failed to reveal even a trace of this element; it was found, however, that the sulphate content varies considerably from one crust to another.

Trona [$Na_2OO_3.NaHCO_3.2H_2O$] is usually associated with thermonatrite and, as noted above, was detected in the preliminary microscopic examination. A small quantity of the mineral was therefore heated, and the gases evolved bubbled through clear baryta water. A heavy precipitate thus formed indicated the presence of bicarbonate in the original material. In order to gain some idea of the relative proportions of normal carbonate and bicarbonate, advantage was taken of the property of the indicator phenolphthalein to lose its colour in the presence of free carbon dioxide. Several samples of the mineral were dissolved in cold water and titrated with hydrochloric acid, using first phenolphthalein to determine the normal carbonate and then methyl-orange to determine the total carbonate content. For a mixture of thermonatrite and trona, if x be the quantity of acid added, using phenolphthalein as the indicator, then the quantity of acid that must be added to complete the titration with methyl-orange can never be greater than $2x$ and only equals $2x$ when no thermonatrite is present. With the given samples, the quantity of acid added in the second part of the titration was always greater than $2x$ and in many cases approached $3x$. The validity of this method of estimation was tested by titrating with the same strength of acid, and under the same conditions solutions of (1) pure

sodium carbonate, and (2) a mixture of equal molecular proportions of sodium carbonate and sodium bicarbonate. The experimental values agreed closely with theory; hence these preliminary titrations showed that free sodium bicarbonate must be present.

Three average samples were now picked out as representative of the whole mass and investigated quantitatively. Each sample, weighing one to two grams, was dissolved in cold water and titrated with a standard solution of hydrochloric acid using two indicators, phenolphthalein and methyl-orange, as described above. A few more drops of hydrochloric acid were added after titration, and the sulphate was precipitated from the hot, weakly acid solution as barium sulphate. The sodium carbonate, bicarbonate, and sulphate contents of the mineral were thus estimated and the water content deduced by subtracting the sum of these constituents from the weight of the original sample. Although no direct determination of the water content was made, support for the deduced figures was obtained by heating five other samples to a dull red heat. The average loss of weight due to evolution of carbon dioxide and water vapour was 21·3 %. This agrees very well with the mean loss to be expected for the three samples analysed, namely, 21·5 %. The values obtained for the water content are therefore sufficiently accurate. The analyses of the three samples are given below:

	1.	2.	3.
Na_2CO_3	30·42	27·92	27·91
$NaHCO_3$	32·42	37·65	39·66
Na_2SO_4	29·68	25·89	24·57
	92·52	91·46	92·54
H_2O (difference) ...	7·48	8·54	7·86
	100·00	100·00	100·00

We have no means of finding out the exact temperature and state of humidity of the atmosphere under which the saline incrustations were formed, though we know from Dr. Johnston-Lavis's observations that the minimum temperature was 73° C., and that the atmosphere was very moist and probably contained appreciable carbon dioxide. We have to consider first whether the normal carbonate is present not only as thermonatrite and trona, but also as natron [$Na_2CO_3.10H_2O$]. It is known that under ordinary conditions natron is only stable below 32·5° C.; above this temperature thermonatrite, the mono-

hydrate, is the stable salt.[1] The vapour-pressure for the balanced system $Na_2CO_3.10H_2O \rightleftharpoons Na_2CO_3.H_2O + 9H_2O$ has been measured at various temperatures.[2] For natron to exist above 70° C. the vapour-pressure must be above 200 mm. From the above analysis it can be seen that there is not enough water to permit all the normal carbonate being present as trona. As a working hypothesis, therefore, it will be assumed that the partial pressure of the water-vapour was not sufficiently high for natron to be present. Similarly, hydrated sodium sulphate [$Na_2SO_4.10H_2O$] under ordinary conditions does not exist above 32·6° C.,[1] and although data do not exist as to its vapour-pressure at high temperatures it is reasonable to assume also in this case that the sodium sulphate is present as the component thenardite [Na_2SO_4]. Finally, the analyses show that even if all the sodium carbonate be present as trona, a possibility denied by the insufficient water content, there would be a considerable amount of free sodium bicarbonate present. Hence it is probable that the analyses represent a mixture of thermonatrite, thenardite, trona, and sodium bicarbonate. The above considerations show that the possibility of the components mirabilite [$Na_2SO_4.10H_2O$] and natron [$Na_2CO_3.10H_2O$] being present is very small. In any case the amounts of these two minerals present must be negligible owing to the low water content. The figures below show the approximate proportions of the minerals assumed to be present in the original mixture.

	Thermonatrite ($Na_2CO_3.H_2O$).	Trona ($Na_2CO_3.NaHCO_3.2H_2O$).	Sodium bicarbonate ($NaHCO_3$).	Thenardite (Na_2SO_4).
No. 1 ...	18	32	20	30
2 ...	7	47	20	26
3 ...	11	39	25	25

The above figures, showing the amounts of thenardite and thermonatrite in the ratio of 2 : 1 to 3 : 1, suggest the possibility of the presence of a double salt, such as $4Na_2SO_4.Na_2CO_3$ (hanksite) or $2Na_2SO_4.Na_2CO_3$.[3] This has been considered, but without definite results.

An optical investigation of the mixture was then resumed. The

[1] A. E. Dunstan and H. Langton, Journ. Chem. Soc. London, 1912, vol. 101, p. 419.

[2] A. F. Gerasimov, Journ. Russ. Physico-Chem. Soc., 1912, vol. 44, p. 1666.

[3] W. A. Caspari, Journ. Chem. Soc. London, 1924, vol. 125, p. 2381; A. F. Rogers, Amer. Journ. Sci., 1926, ser. 5, vol. 11, p. 473. [Min. Abstr., vol. 3, p. 162.]

majority of the fragments, viewed under the microscope, give straight extinction with negative elongation. The maximum refractive index for some is 1·524 and for others just greater than 1·540. The latter correspond to trona and the former to thermonatrite. Trona was found not only in the compact mass but intergrown or cemented together with the thermonatrite crystals lining the cavities. Plentiful irregularly-shaped masses determined as thenardite were found, but no traces of minerals with all the refractive indices lower than 1·469 (olive-oil), such as natron or mirabilite. The thenardite in some places seems to consist of a transparent core surrounded by material which has effloresced. The remaining component was readily distinguished from all those above mentioned. Small crystals giving an extinction angle of 20° to an edge, the direction of which is negative, are found both in the compact mass and at the surface. They possess very high birefringence and the maximum refractive index is only a little less than 1·590. Artificially prepared sodium bicarbonate crystals were examined side by side and gave exactly the same characteristics. The chemical and optical data prove conclusively the presence of free sodium bicarbonate.

The results of analysis show that the amount of free sodium bicarbonate present cannot be less than 20 %. An attempt was therefore made to concentrate this compound by separating the lighter and heavier components with mixtures of methylene iodide and benzene of varying specific gravities. Such a mixture was adjusted till a crystal of trona from Lake Magadi, Kenya Colony, just floated. Most of the ' thermokalite ' introduced into the mixture floated just below the trona crystal. The smallest particles at the bottom of this layer were withdrawn and examined optically. They were found to contain a larger quantity of sodium bicarbonate than before separation, but most of the material seemed to be intergrown with trona or thermonatrite. Some crystals appear to have an interior of thermonatrite and an outer zone of sodium bicarbonate. Unfortunately even the larger crystals of sodium bicarbonate were easily visible only with a $\frac{1}{4}$-inch objective ; it therefore appeared unprofitable to attempt the more difficult separation of trona from the sodium bicarbonate. However, we may conclude that the specific gravity of the sodium bicarbonate is just greater than that of the trona crystals. Walther found the specific gravity of Lake Magadi trona to be 2·14.[1] The value for sodium bicarbonate is probably therefore nearer 2·2. It is interesting

[1] P. Walther, Amer. Min., 1922, vol. 7, pp. 86–88. [Min. Abstr., vol. 2, p. 47.]

to note that the specific gravity of artificial sodium bicarbonate crystals is 2·22.[1]

Physically and chemically, then, the so-called 'thermokalite' would appear to be a mixture of trona, thermonatrite, sodium bicarbonate, and thenardite. The name 'thermokalite' is therefore unnecessary. The crusts vary considerably in sulphate content. In one case the amount of sodium sulphate falls to 4 %, and the crust seems to be composed almost entirely of trona. So far as I am aware this is the first reported occurrence of such minerals from the Phlegrean Fields. The existence of sodium bicarbonate in these saline incrustations as a mineral will now be discussed.

It is mentioned above that trona has not been previously reported from Campi Phlegraei. Trona occurs both at Vesuvius and Etna, but complete analyses have not been published. V. R. Matteucci examined a white crystalline substance from Fosse Grande, Vesuvius, and found a large quantity of sodium bicarbonate present. He apparently did not decide whether the sodium bicarbonate was combined as trona or whether it represented a new species.[2] F. Zambonini found crystals of trona in the cavities of a leucite-tephrite at the base of the crater in the Atrio del Cavallo, Vesuvius, near the lava flow of 1895. He obtained sufficient optical and crystallographic data to decide definitely that the mineral was trona.[3] He also heated about one-tenth of a gram of the material and found the loss in weight to agree closely with that to be expected for trona. F. S. Starrabba, in an account of sodium carbonate minerals from Etna,[4] makes no mention of free sodium bicarbonate. He also gives no complete analysis for trona and he observes that the loss of weight on heating is higher than the theoretical value for trona. He attributes this to admixture with natron. It may be noted here that admixture with sodium bicarbonate would also increase the loss of weight on heating. The data on Italian trona are therefore very scanty.

Numerous analyses, however, have been published for trona from other localities. Doelter, for instance, gives in his 'Handbuch der Mineralchemie' 1912, vol. 1, part 1, pp. 186–187, a list of twenty from various places. He points out that whereas all the recent

[1] F. Stolba, Journ. Prakt. Chem., 1866, vol. 97, p. 503.

[2] V. R. Matteucci, Sul bicarbonato sodico prodottosi sulle lave dell'eruzione vesuviana principiata il 3 luglio 1895. Rend. Accad. Sci. Fis. Mat. Napoli, 1897, ser. 3, vol. 3 (= Ann. 36), p. 223.

[3] F. Zambonini, Atti Accad. Sci. Fis. Mat. Napoli, 1908, ser. 2, vol. 13, p. 38.

[4] F. S. Starrabba, Revista Min. Crist. Ital., 1913, vol. 42, p. 51.

analyses and many of the earlier ones support Laurent's formula (1852), $Na_2CO_3.NaHCO_3.2H_2O$, a few agree with Klaproth's formula (1802), namely $Na_2CO_3.2NaHCO_3 . 3H_2O$. The analyses of trona from Egypt by Popp [1] made in 1870 are the only analyses of recent times which support the latter formula. Nevertheless, for some time all analyses of trona were reduced to the sesquicarbonate formula. It was Chatard [2] who showed in 1889 that his own analyses of trona from Owen's Lake, California, and most of the earlier analyses, except Popp's, when recalculated, supported much more satisfactorily the now generally accepted formula, namely, $Na_2CO_3.NaHCO_3.2H_2O$. Doelter rightly concludes that all naturally occurring trona whose composition cannot be represented by this formula must be mixtures of trona with other sodium carbonates. If we recalculate all these analyses which do not agree, we find some of them to be mixtures of trona with thermonatrite or natron, or both; but a few remain which cannot be explained in this way. Those in fact which support Klaproth's formula must be mixtures of trona, thermonatrite or natron, and free sodium bicarbonate. If the analyses of Klaproth and Popp be recalculated, using the correct formula for trona, the amount of free sodium bicarbonate present varies from 15 to 20 %. Unless Klaproth and Popp were grossly inaccurate in their methods they must have been analysing a mixture containing, in addition to trona, free sodium bicarbonate. Recently, P. Walther (loc. cit.), whilst examining the sodium carbonate deposits of the Magadi Lakes, Kenya Colony, discovered in the salt crusts of Little Magadi, bladed crystals, harder than trona, composed of very nearly pure sodium bicarbonate. He did not obtain any physical data on these crystals and refrained with commendable caution from giving a new name. This short review of what is known about the occurrence of sodium bicarbonate in nature is, to some extent, confirmatory evidence for the existence of sodium bicarbonate as a mineral. In my opinion the physical and chemical data obtained in working on the so-called 'thermokalite' clearly prove the presence of a considerable quantity, at least 20 %, of free sodium bicarbonate and justify the naming of a new mineral.

Dr. L. J. Spencer has very kindly suggested an ingenious name, *Nahcolite*. The significance of the name is appreciated when written NaHCO-lite, and it gives a useful 'memoria technica' for distinguishing

[1] O. Popp, Ann. Chem. Pharm., 1870, vol. 155, p. 248.

[2] T. M. Chatard, Amer. Journ. Sci., 1889, ser. 3, vol. 38, p. 59.

still another sodium carbonate mineral. It is unfortunate that in these crusts the nahcolite occurs in such small crystals and mixed with so many other salts. The mineral, though adequate for determinative purposes, is obviously unsuitable for crystallographic or accurate optical measurements. It is also difficult to separate sufficient from the original masses for a really reliable analysis.

In conclusion, some remarks, chiefly speculative, will be made on the genesis of nahcolite at Baia. The mode of formation of the saline crusts in the cuniculi is not definitely known. The material of which the hill is made, viz. a pumiceous tuff, has been acted upon considerably by the fumarolic gases of the Phlegrean Fields. The tuff at the surface of the tunnel was friable and quite decomposed. It is a possibility, therefore, that the saline incrustation is an efflorescence on the walls of tuff forming the cuniculus. On the other hand, the deposits equally well suggest evaporation products from the water of the hot springs. Whilst it is not certain how the 'thermokalite' was actually formed, there is more hope of discussing the conditions under which the several components of the mixture might be expected to appear. We have already dealt with the conditions of formation of two components, thenardite and thermonatrite. It was necessary to consider the high temperature and the humidity of the air of the cuniculus. In order to explain the formation and stability of nahcolite, a further constituent of the air in the cuniculus must be considered, viz. carbon dioxide. Brun's analyses of gases contained in Vesuvian lavas[1] and similar work of Shepherd and Merwin on the Mt. Pelée lavas[2] show how important a constituent is this gas. The Grotto del Cane, near Naples, is a famous instance of continuous evolution of carbon dioxide from the surrounding rock. The gas has also been observed bubbling up through thermal springs of this locality. The high temperature of the volcanic hill backing Baia is a favourable condition for evolution of carbon dioxide and, prior to the increased ventilation brought about by tunnelling for the Cumana railway, the Roman cuniculi must have been excellent receptables for the gas. Even after tunnelling, we know from Dr. Johnston-Lavis's observations, there was considerable carbon dioxide inside the cuniculus. Whether, then, we regard the incrusta-

[1] A. Brun, Recherches sur l'exhalaison volcanique. Geneva and Paris, 1911, pp. 95–97.

[2] E. S. Shepherd and H. E. Merwin, Journ. Geol. Chicago, 1921, vol. 35, pp. 76–116. [Min. Abstr., vol. 3, p. 502.]

tions as formed by the evaporation of the hot springs containing plentiful carbon dioxide in solution, or whether we consider the action of carbon dioxide on an efflorescence coating the walls of the cuniculus, in either case the conditions must have been suitable for the formation of trona. In order to decide whether nahcolite could have been formed and maintained in a stable condition at such a temperature we ought to know whether the partial pressures of the water-vapour and carbon dioxide were sufficiently high. Although this knowledge is lacking, it is interesting to calculate the order of magnitude of the necessary pressures. Many experimenters have studied the decomposition of sodium bicarbonate, but their data vary considerably. The most reliable work of recent date is that carried out by Caven and Sand[1] on the alkali bicarbonates. One system studied carefully was:

$$2NaHCO_3 \rightleftharpoons Na_2CO_3 + H_2O + CO_2$$

The experimental values of the vapour-pressure (p) at various temperatures over the range 85°–110° C. agreed with the theoretical formula

$$\log p = 11{\cdot}8185 - \frac{3340}{T}$$, where T is the absolute temperature.

At temperatures below 85° C. the results were vitiated by the formation of crusts on the surface, which greatly retard the velocity of the reaction. Days were taken, even at temperatures of about 90° C., to obtain equilibrium on raising the temperature. The authors consider that this difficulty probably accounts for the lack of agreement amongst previous experimenters. We can probably obtain a fairly accurate calculated value for p at 70° C., however, by using their formula. The vapour-pressure of the system at this temperature is roughly one-sixth of an atmosphere. Hence in order to maintain the bicarbonate in a stable condition at such a temperature the amount of carbon dioxide in the air must be at least 8 % by volume. However, there were probably at least two more components present, viz. thermonatrite and trona. The authors failed to obtain experimental values for a four-component system, but their calculations show that the partial pressure of the carbon dioxide is about 30 mm. at 70° C. It is to be noted that the necessary pressure of water-vapour, 120 mm., is much less than the vapour-pressure of natron or mirabilite at this

[1] R. M. Caven and H. J. S. Sand, Journ. Chem. Soc. London, 1911, vol. 99, pp. 1359–1369.

temperature, (viz. over 200 mm.). That is, the water-vapour necessary to maintain a system containing nahcolite and thermonatrite in equilibrium is not sufficient to form natron or mirabilite. We have no data for a system containing trona in addition, but it can be shown that the approximate value of 30 mm. for the partial pressure of carbon dioxide obtained above for the four-component system would not be materially altered. Thus, as nahcolite was found at a temperature probably higher than 70° C., the amount of carbon dioxide present in the cuniculus must have been about 4 % by volume. At 90° C., however, this figure would have to be about 16 %.

Caven and Sand's work therefore enables us to make an approximate guess as to the condition of the atmosphere in the cuniculus. Their work also throws light upon a further matter. It is a general opinion that sodium bicarbonate can never exist as a mineral under ordinary conditions. If it be formed then it is rapidly and completely converted into trona. Only the presence of excess carbon dioxide in the atmosphere would render it stable. Such an opinion is probably based on experiments on the decomposition of sodium bicarbonate. The work of Caven and Sand indicates the difficulty of obtaining reliable data at low temperatures owing to 'retardation'. If we make use of their formula at room temperatures we find that the partial pressure of carbon dioxide necessary to maintain the stability of nahcolite at 20° C. is of the same order as that exerted by the normal carbon dioxide content of the atmosphere, viz. 0·03 % to 0·3 % by volume. This, however, is not an experimental result. Until the decomposition pressure of sodium bicarbonate has been measured at ordinary temperatures no accurate conclusions are possible. The formation of crusts referred to by Caven and Sand is very important. At ordinary temperatures this 'retarding' factor would prevent equilibrium from being reached for a long time. Thus fluctuations in the carbon dioxide content of the atmosphere would have no effect once these crusts were formed. It is possible that even when the pressure exerted by the carbon dioxide of the atmosphere is lower than the partial pressure of the bicarbonate, decomposition after a time will be arrested and the reaction will not proceed to completion. In confirmation of this it is known that artificial sodium bicarbonate when exposed to the atmosphere gives off carbon dioxide till a certain proportion of the normal carbonate is formed, when further decomposition is only effected by leaching out the

sodium carbonate. This is, at all events, a probable explanation of the presence of at least 20 % nahcolite in a saline incrustation collected about forty years ago.

In conclusion, I should like to thank the Keeper of Minerals, Dr. L. J. Spencer, for his continual assistance and helpful criticism. Without his aid the work would have been full of omissions.

An investigation into the piezo-electric effect of diamond.

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[Read November 6, 1928.]

Introduction.—Opinion is divided as to the true crystal symmetry of diamond. Some authors, notably Fersman and Goldschmidt,[1] who have investigated its morphological and etch characters, consider it is always hemihedral, whilst others, by the same methods, have obtained results which indicate holohedrism. Early work by A. Artom[2] showed that it was seldom piezo-electric, but more frequently pyro-electric. Van der Veen[3] also carried out a very thorough investigation and found no piezo- or pyro-electricity in his five diamonds. These were octahedral in shape, and not very suitable for this experiment.

Two diamonds flattened parallel to the octahedron face, and therefore specially suited to the work, have recently been lent to the Department by the kindness of Mr. Alpheus F. Williams of the De Beers Mines, South Africa, who asked that they should be tested for any piezo-electric effect. It was possible by means of the simple method described below to show that the diamonds were not piezo-electric within the accuracy of the experiment. The essential feature of the method is the way in which pressure is applied to the diamond. As it is most important to maintain the insulated portions quite steady during the application of the force, magnetic attraction was employed rather than mechanical means. This was successful in obviating all but a very slight movement, although the total force obtained in this way was only 300 grams.

Experimental method.—The apparatus (fig. 1) consists of an electromagnet, on the pole piece of which are placed a plate of amber 1·5 mm. thick and a disk of soft iron 1·25 cm. in diameter and 1 mm. thick. The diamond plate is placed on top of this disk, and on top of the

[1] A. von Fersmann and V. Goldschmidt, Der Diamant. Heidelberg, 1911.
[2] A. Artom, Atti R. Accad. Sci. Torino, 1902, vol. 37, p. 667.
[3] A. L. W. E. van der Veen, Zeits. Kryst. Min., 1913, vol. 51, p. 545.

diamond a long pole piece which is attracted downwards when the current is passed through the coils of the magnet. A long pole piece is necessary because in this way a much greater force is obtained. In these experiments a current of 4 ampères was used, and this gave a force of attraction of about 300 grams between the upper pole piece and the magnet when the diamond was in position. To measure the charge developed on switching on the current, it would at first sight seem sufficient to connect the upper pole piece to the electrometer and the lower disk to earth. Then if there should be any charges developed due to causes other than the piezo-electric effect it would seem that they could be eliminated by reversing the diamond. It was found that this simple method was not adequate to differentiate between the causes contributing to the deflexion in any given case. These are partly due to slight irregularities on the surface of the diamond and pole piece, giving rise to a very slight 'wobble'. If this were the same for the diamond both in its first position and also when reversed it would not matter; but since this cannot be so, it is necessary to devise a means of eliminating this effect. This difficulty can be expressed symbolically as follows. If D is the effect of the diamond and W_1 the deflexion due to the 'wobble' in the first position, $-D$ will be the effect when the diamond is reversed and W_2 the second wobble. Then the deflexions, x_1, x_2, will be given by

$$x_1 = D + W_1 \text{ and } x_2 = -D + W_2.$$

It is clear that since we have two equations and three unknowns, the value of D cannot be found. To overcome this difficulty the amber plate and lower electrode indicated in the figure were introduced. Wires from the upper and lower electrodes were joined alternately to the electrometer, which was of the sensitive Compton type, by means of two mercury cups. The method of conducting an experiment was as follows. With the diamond in its first position three deflexions were measured: (*a*) with the upper pole piece connected to the electrometer and the lower connected to earth; (*b*) the lower pole connected to the electrometer and the upper to earth; (*c*) both electrodes connected to the electrometer. The diamond was then reversed and these three observations repeated. There are thus six observations in all for each measurement of the piezo-electric effect, which are combined in the following way. The 'wobble' need not be the same for the diamond in its two positions, and hence it is necessary to allow for two values, W_1, W_2. In addition to the

'wobble', there is a small induced effect independent of which electrode happens to be connected to the electrometer. This may be different for the diamond in its two positions, and therefore two terms, X_1, X_2, are introduced to take account of this. Lastly, the amber which is used to insulate the lower iron disk from the magnet may give rise to a constant piezo-electric effect, independent of everything except the total pressure applied, and this is denoted by A.

We may thus write down a series of equations connecting these

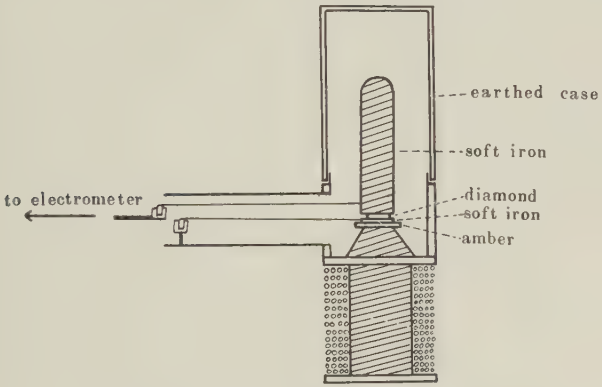

FIG. 1. Diagram of apparatus for testing piezo-electric effect.

constants with the six observed deflexions. With the diamond in one position and the upper electrode connected to the electrometer, we have

$$x_1 = D + W_1 + X_1.$$

When the lower electrode is joined to the electrometer, then

$$x_2 = A - D + X_1,$$

and when both electrodes are connected together

$$x_3 = A + W_1 + X_1.$$

For the diamond in its reversed position we have a similar set of three equations, the sign of D being reversed and W_2, X_2 substituted for W_1, X_1.

$$x_4 = -D + W_2 + X_2;$$
$$x_5 = A + D + X_2;$$
$$x_6 = A + W_2 + X_2.$$

With these six equations we can solve the equations for the six unknowns, including the value of D.

Experimental results.—One of the diamonds used for the experiments is a plate 0·121 cm. thick, the large face being parallel to the octahedron, and it is apparently untwinned. It is lozenge-shaped, the maximum length being 10 mm. and the minimum 8 mm. Under the polarizing microscope it appears to be quite isotropic and also shows some small triangular markings having their edges inclined at 60° to the octahedron edges. The second is a spinel-twin 0·219 cm. thick, the large face being parallel to the octahedron. It is triangular in shape, the length of the side being 8 mm. Under the polarizing microscope this specimen shows anomalous double refraction.

Owing to the minute electrical effects concerned in these experiments it was necessary to use the electrometer in as sensitive a condition as convenient, which was found to be 7,000 divisions per volt. With 4 ampères circulating in the electromagnet the deflexion obtainable with the quartz section was 460 mm. Six sets of observations were made on the thin diamond, and the maximum deflexion found for it after applying the reduction given by the six equations above was 1·3 mm. The experimental error cannot be determined accurately, but is probably about 2 mm. Three sets of observations were made on the other diamond. In this case, because of the smaller area of its octahedron face, it was much more difficult to avoid 'wobble'. The maximum value of D was found to be 5 mm., and the experimental error was about the same value. Thus we may conclude that within the limit of error the diamond shows no piezoelectric effect, and that if there is an effect it is less than 1/200th part of that of quartz cut perpendicular to an electric axis.

Discussion.—The hemihedral character of diamond has been investigated by a number of methods. Fersman and Goldschmidt (op. cit.), in their treatise on the diamond, come to the conclusion that the diamond is certainly hemihedral, basing their arguments on morphological and etch characters. In some unpublished work, Mr. Alpheus F. Williams has shown by the same methods that the diamond is not necessarily hemihedral. Mrs. K. Lonsdale [1] has recently shown that the crystal structures of many of the carbon compounds, and also of carbon in the free state, can be explained on the assumption that the carbon atom has two different types of valency. If this be true it is probable, though not certain, that the diamond would show piezoelectric effects. Elings and Terpstra [2] have recently investigated the

[1] K. Lonsdale (née Yardley), Phil. Mag., 1928, ser. 7, vol. 6, p. 433.
[2] S. B. Elings and P. Terpstra, Zeits. Krist., 1928, vol. 67, p. 279.

piezo-electric effect in diamond and many other compounds by a method involving triode valves and they observed no effect for diamond. I have also carried out a similar experiment with diamond with like result. The measurements of van der Veen [1] showed that the effect in his diamonds could not be greater than 1/600th of that in quartz. The experiment described here, though not so sensitive, indicates that the effect must be of the same order if it exists at all. Therefore, in conclusion, we may say that some physical properties of the diamond demand holohedral characters and that all others can be reconciled with that symmetry.

I wish to thank Mr. Alpheus F. Williams for the loan of the diamonds, Mr. E. C. Bullard for assistance in some of the experimental work, and Mr. N. Lanham for the preparation of the quartz section. This section, used for comparison, was 0·10 cm. thick and was cut perpendicular to an electric axis.

[1] A. L. W. E. van der Veen, Zeits. Kryst. Min., 1913, vol. 51, p. 545.

On the atomic volume relations in certain isomorphous series. III.

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[Read June 12, 1928.]

ACCURATE knowledge of the compressibility of solids was first due in a large measure to the investigations of T. W. Richards, who showed that the pressure-volume curves for sodium and potassium approximate in form to rectangular hyperbolae,[2] that the compressibilities of the free alkali metals are nearly proportional to the atomic volumes, and that the atoms can be treated as filling the available space. Richards then endeavoured to calculate the relative volumes of the combined elements in the alkali halides, assuming that the large contraction which takes place on forming the compound was due to an internal pressure which affected equally the alkali metal and the halogen. The values obtained in this special case agree with those obtained in other ways, but Richards pointed out that his proposed method was not of general application; consideration of a wider range of compounds showed that the partial volumes of the elements in combination could not be derived solely by the operation of a common internal pressure, but must be influenced also by factors

[1] Communicated by permission of the Director. Previous papers of this series in Min. Mag., 1927, vol. 21, p. 277; 1928, vol. 21, p. 480.

[2] T. W. Richards, Journ. Amer. Chem. Soc., 1923, vol. 45, pp. 422–437. Additional data for the compressibilities have been made available in the observations of Adams, Johnson and Williamson, Bridgeman, and Slater. The data were studied extensively by Richards in a series of papers of which a brief account is given in Trans. Faraday Soc., 1928, vol. 24, pp. 53–164, 165–179. A fuller account will be found in Journ. de Chimie Physique, February, 1928, vol. 25, pp. 83–119. News of the death of this distinguished investigator was received only a few weeks after the latter summary appeared ('Nature', May 5, 1928). In his later work Richards developed the formula $pv = k$ into relationships of the type $(p+\Pi)(v-b) = k$, but for the present purpose the simpler formula affords an extensive agreement with the data, and will be used as a first approximation to the real form of the pressure-volume curve.

affecting each element independently: for example, by the state of chemical combination.

In the earlier sections of the present paper the volume-relations of the salts derived from certain eutropic series of elements were shown to be consistent with the assumption that when the atoms in a eutropic series are combined with a given radicle, their volumes are related by a common factor to the corresponding volumes in the free state or when combined with another radicle. This at once suggests a further analogy with the behaviour of a perfect gas under varying temperature and pressure, and it has therefore seemed of interest to examine upon what conditions the volume-relations can be reconciled with the known data for the compressibility of the elements. It will be shown that pressure-volume relations of the type $pv = k$, already proved experimentally by Richards for the free alkali metals, can be used also to calculate the volumes and compressibilities of the alkali halides, by adopting a different value of k for the eutropic series of elements in the combined state. The combined elements behave to a close approximation as regions of a perfect gas which together completely fill the crystal lattice, without interstitial spaces.

Relevant formulae.—The properties of the equation $pv = k$ are, of course, well known. The curves form a family of rectangular hyperbolae, the compressibility being given by $\beta = 1/v \,.\, dv/dp = -1/p$. The compressibility is thus independent of k, i. e. it is the same for all the hyperbolae at a given pressure. The corresponding internal pressure for an element can therefore be assigned at once as approximately the reciprocal of the compressibility. For a gram atom, $K = pV = -V/\beta$, where V is the atomic volume; thus the compressibilities of substances with K in common are proportional to the atomic volumes, as was shown experimentally by Richards for the eutropic alkali metals.

Direct compression of the alkali metals.—For $pv = k$, $\log p + \log v = \log k$. If the 'internal pressure' of an element is given by $-1/\beta$ (above) this value must be added to the external pressure applied. Bridgeman's data are quoted in the table below. For the first 1,000 megabars, for sodium, $\beta = -15{\cdot}0 \times 10^{-6}$ per megabar; for potassium, $\beta = -33{\cdot}0 \times 10^{-6}$. The corresponding pressures $(-1/\beta)$ are 66·65 and 30·31 thousand megabars. These have been added to the external pressures applied, which ranged from 0 to 12,000 megabars.

Sodium (30° C.).[1]			Potassium (45° C.).[1]		
p.	v.	$\log p+\log v$.	p.	v.	$\log p+\log v$.
66	1·0000	1·8238	30	1·0000	1·4816
68	0·9701	1·8234	32	0·9385	1·4817
70	0·9430	1·8236	34	0·8905	1·4850
72	0·9181	1·8241	36	0·8496	1·4892
74	0·8950	1·8248	38	0·8123	1·4930
76	0·8737	1·8259	40	0·7778	1·4964
78	0·8535	1·8269	42	0·7456	1·4989

The total in the last columns at first diminishes and then steadily increases. Closer constancy is obtained over the higher pressures if somewhat higher internal pressures are assigned to the metals, so that the values become those given in the following table:

Sodium (30° C.).			Potassium (45° C.).		
p.	v.	$\log p+\log v$.	p.	v.	$\log p+\log v$.
74	1·0000	1·8692	37	1·0000	1·5682
79	0·9303	1·8663	42	0·8694	1·5620
81	0·9063	1·8658	44	0·8305	1·5627
83	0·8841	1·8656	46	0·7947	1·5630
86	0·8535	1·8657	49	0·7456	1·5627

Over the latter half of the range of applied pressure the agreement is now almost perfect. As the pressure falls to atmospheric, the volume increases slightly above that required by $pv = k$, but the extent of this deviation is remarkably small, being of the order of 1 % of the volume. The internal pressures are, for sodium, 74,000 megabars; for potassium, 37,000 megabars. For a gram atom, for sodium, $K = 1{\cdot}70 \times 10^6$; for potassium, $K = 1{\cdot}76 \times 10^6$.

Relation of compressibility to atomic volume in eutropic series.—The degree of constancy of K in each series may be seen from the following values:

Element.	Atomic volume.	Compressibility per megabar ($\times -10^6$).	$K = -V/\beta$ ($\times 10^{-6}$).
Cs	70·5	61	1·18
Rb	55·9	40	1·40
K	45·4	31·7	1·43
Na	23·7	15·6	1·52
Li	13·0	9·0	1·44
K	45·8	(27·0)	1·70
Na	23·7	(13·5)	1·76
Ag	10·23	0·97	10·5
Cu	7·08	0·75	9·4
Sr	36·0	8·35	4·31
Ca	25·9	5·84	4·44
Cd	12·98	2·24	5·8
Zn	9·02	1·74	5·18

[1] P. W. Bridgeman, Proc. Amer. Acad., 1923, vol. 58, pp. 165–242.

The two additional values for sodium and potassium are those derived above from the data at higher pressures; they indicate that the curves for the two elements approach tangentially to the same hyperbola, with which they appear to coincide under high pressure.

For the other alkali metals the values for K, though somewhat lower than the preceding because they were obtained by using the compressibilities at atmospheric pressure, point to a similar relation: the pressure-volume curves coincide very closely with one hyperbola for which $pV = 1{\cdot}7$. The same is true in the other eutropic groups, though the values for K differ widely. The constancy of K offers a definition of eutropy which is alternative to that based upon the rule of proportional differences (Part I, p. 279).

In this connexion it may be of interest to consider for a moment the properties of the various substances in one of the large isostructural groups. As an example, there is in Ewald's 'Strukturbericht'[1] a very full list of substances that crystallize in the face-centred cubic lattice. Structurally, from the standpoint of X-ray research, the space-lattice is the same in all cases, so that they form an isostructural or 'homotaxial' group. But it will be seen from the following table that, when classified according to the values of K, they fall into sub-groups which correspond with the eutropic series, though in some cases only one member of a series may be represented.

Type A 1.—

Element ...	Cu.	Ag.	Au.	Ca.	Al.	Pb.
K	9·4	10·5	17·3	4·4	7·3	7·62
Element ...	Co.	Ni.	Rh.	Pd.	Ir.	Pt.
K	20·4	20·2	35·8	27·4	50·8	40·3

Rate of change of compressibility.—For $pv = k$, the rate of change of β is given by $d\beta/dp = -d/dp\,(1/p) = \beta^2$. The change is not very easily measurable. Even for sodium and potassium the changes in β per 1,000 megabars are only 6 and 34 units in the third significant figure. Values taken directly from the observed pv curves (see below) show that at high pressures the second differential, like the compressibility, is in agreement with the value required by the simple formula, i. e. the pv curve really coincides with the ideal hyperbola; but at low pressures the upward trend of the observed curve, already noted, is most clearly evidenced in the difference between the observed values for $d\beta/dp$ and those calculated (β^2) for the tangent hyperbola.

[1] Zeits. Krist., 1927, vol. 65, appendix, p. 14.

Rate of change of compressibility for Na and K.

	$\beta \times -10^6$ (observed).	$d\beta/dp \times 10^9$ (observed).	$\beta^2 \times 10^9$
Na at 10,000 megabars ...	11·4	0·2	0·13
K ,, ,, ,, ...	21·7	0·6	0·47
Na at atmosphere	15·3	0·6	0·24
K ,, ,, ...	33·0	3·4	1·09

The metals behave as though they contained small amounts of included gas, which become negligible at higher pressures; but the volume to be assigned, about 1 %, seems higher than could be due to such a cause, and it is probable that the effect is a true property of the crystal, possibly related to the heat movements of the atoms, which still have an appreciable amplitude.[1]

The existence of a general, possibly single-valued, relation between the compressibility of the elements and the rate of change of compressibility with pressure has been suggested by Adams.[2] For $pv = k$, $d\beta/dp = \beta^2$, a relation independent of the nature of the element. Adams plotted the difference $\Delta\beta$ due to a change in pressure of 10,000 megabars; in this case $\Delta\beta = \Delta p/p_0(p_0 + \Delta p) = \Delta p\beta_0/(1/\beta_0 + \Delta p)$, a relation also independent of the nature of the element. As Adams remarks, the uncertainty of the data prevents a rigorous comparison; the values of $\Delta\beta$ for the less compressible elements are still of the right order, but they are larger than is required by theory, probably owing to the same cause as the corresponding anomaly for the alkali metals near atmospheric pressures.

Calculation of compressibility for the alkali halides.—At first it appears surprising that, while the compressibility of metallic potassium is -33×10^{-6}, that of potassium chloride is only $-5{\cdot}6 \times 10^{-6}$. It is true that the volume calculated for the metals in these salts is only about half that in the free state; but if the metals are compressed along their hyperbola to about half their volume, as Richards at first suggested, their compressibility is only reduced to about half its initial value, and is still much too high. It will be shown, however, that a simultaneous solution for both volumes and compressibilities can be obtained if the whole group of metals is removed to another hyperbola, i. e. if the effects of chemical combination and of removal to another space-lattice are comprised in an alteration of the con-

[1] R. W. James and Elsie M. Firth, Proc. Roy. Soc. London, Ser. A, 1927, vol. 117, pp. 62–87.

[2] L. H. Adams, Journ. Washington Acad. Sci., 1927, vol. 17, pp. 529–533.

stant K, the volumes being diminished proportionally in accordance with the rule of proportional differences. If v_1 is the new value of V and K_1 the corresponding new value of K, the compressibility of the metal is given by $\beta_1 = -v_1/K_1$. The compressibility for the halogen can then be calculated from the observed compressibility of the salt. For an arbitrary new value of K for the metals, the compressibilities that must be assigned to the halogens are usually quite improbable, being often negative; but the following table will show that for the special value $K_1 = 4{\cdot}0$ for the metals, a consistent set of values is obtained for the compressibilities of the halogens in the alkali halides, these in their turn being subject to a relation, $pv = K_2$, where K_2 is a constant for the eutropic series F, Cl, &c.

Partial volumes and compressibilities in the alkali halides.[1]

	Partial volumes.		$\beta_1 = -v_1/K_1$ $(K_1 = 41 \times 0^6)$.	β (Salt).	β_2 (Halogen).	
Salt.	Metal.	Halogen.	(Metal). $\times -10^6$.	Observed. $\times -10^6$.	Calculated. $\times -10^6$.	K_2 (Halogen). $\times 10^{-6}$.
LiF	6·2	5·1	1·55	1·53	1·5	3·4
LiCl	7·7	12·7	1·92	3·41	4·3	2·95
LiBr	8·6	16·3	2·15	4·31	5·4	3·02
NaCl	14·0	12·7	3·50	4·20	5·0	2·54
NaBr	15·7	16·3	3·92	5·08	6·2	2·63
KF	18·16	4·6	4·54	3·31	—	—
KCl	24·6	12·5	6·15	5·63	4·6	2·72
KBr	26·0	17·0	6·50	6·70	7·0	2·42
KI	28·1	24·5	7·02	8·54	10·3	2·38
RbBr	32·0	17·0	8·00	7·94	7·8	2·18
RbI	34·6	24·5	8·65	9·58	10·89	2·25

The first column shows those halides for which data are available. Columns 2 and 3 give the partial volumes calculated by the rule of proportional differences (Part I of the present paper). According to the theory just outlined, the compressibilities of the metals should be calculable from the volumes by the relation $\beta_1 = -v_1/K_1$. The most satisfactory value of K_1 for the metals in these salts is found by trial to be 4·0,[2] and the resulting compressibilities are shown in column 4. The observed compressibility of the crystal (column 5) will be the mean (weighted for the relative volumes concerned) of those for the metal and the halogen. The values required for the compressibilities of the combined halogens can thus be calculated and are those shown

[1] J. C. Slater, Physical Review, 1924, vol. 23, pp. 488–500.

[2] Both 3·5 and 4·5 lead to less satisfactory results for the halogens.

in column 6. These in their turn should be related to the partial volumes of the halogens (column 3), so that $-v_2/\beta_2 = K_2$; for the halogens are, like the metals, a eutropic group of elements. Column 7 contains the values of K_2; in view of the wide range of the data the constancy appears satisfactory; a small diminution in K_2 is probably the result of the anomalous increment in the volume-differences (Part I, p. 282), for the volumes are not perfectly additive in this very wide isomorphous series. An irregular value for potassium fluoride is almost certainly due to a special cause, possibly a slight error in the reported data.

A very interesting confirmation of the compressibilities here assigned to the alkali metals (in the halides) is the estimate given by L. H. Adams and E. D. Williamson,[1] who find by direct computation that the compressibility of K_2O and Na_2O in certain minerals must be about $6{\cdot}0 \times 10^{-6}$. The volumes here assigned to the metals in the halides do not greatly differ from those in the minerals in question (mica,[2] &c.), being in both cases about half those in the free state; it is therefore permissible to compare this value—a rough average—with the figures 6·5 and 3·5 for potassium and sodium in the foregoing table.

[1] L. H. Adams and E. D. Williamson, Journ. Franklin Inst., 1923, vol. 195, p. 494.

[2] A. F. Hallimond, Min. Mag., 1927, vol. 21, p. 204.

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